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Article

Are rural households in the Kargil district of Ladakh multidimensionally poor?

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Abstract: Reducing poverty and inequality of any kind is a pre-condition for achieving improved quality of life and overall well-being of the masses for attaining sustainable development. In this pre-text, this paper examines the multidimensional aspects of poverty in the rural households of the Kargil district of Ladakh, India. The analysis of primary data collected from 315 sample households using the Alkire-Foster method reveals the presence of multidimensional poverty in about 66.03% of households. In contrast, about 33.33% of households are vulnerable to such poverty. It is found that deprivations in education, standard of living, nature of employment, women empowerment, and social security dimensions are critical in contributing to multidimensional poverty in the district. Besides, the estimation of the multiple regression equation infers that the intensity of multidimensional poverty is positively influenced by the age of the household head and family size, and negatively influenced by monthly food and non-food expenditures. Therefore, the policy focus is required on all these aspects to help households escape from multidimensional poverty so that inclusive growth can be ensured.

Keywords: multidimensional poverty; household poverty; Kargil; India

1. Introduction

Recently, India has envisioned its mission to become Viksit Bharat by 2047 with the lowest poverty and inequality. In this connection, it is pertinent to cite a report released by the NITI Aayog[1] that India has been successful in reducing poverty from 29.17% in 2013–2014 to 11.28% in 2022–2023 in the multidimensional framework. This concept of multidimensional poverty tries to capture the deprivations of people with the help of multiple indicators instead of measuring poverty in terms of household income or consumption expenditure [1]. The primary argument behind the concept of multidimensional poverty is that enhancing people's capabilities rather than achieving economic progress is the true pre-requisite for Viksit Bharat@2047. Since the welfare of households depends on employment, housing, sanitation, health, education etc. and only income or consumption expenditure cannot appropriately capture the well-being of the masses, measuring poverty in a multidimensional framework is quite justified [2]. It's advantageous in (a) directly capturing the deprivations of people; (b) including both monetary and non-monetary dimensions of well-being; (c) justifying poverty as a measure of the outcomes of economic progress; (d) containing the distributional aspects of national income and (e) reflecting the outcomes of various development initiatives of the government.

It is with this backdrop, that this paper is an attempt to answer the research questions: Whether rural households in the Kargil district of Ladakh are multidimensionally poor, and what are the factors significantly determining the intensity of multidimensional poverty in the district? The recent report released by NITI Aayog[2] states that about 12.70% of the population in Ladakh was multidimensionally poor in 2015–2016, and this number has been reduced to 3.53% in 2019–2021 which has further been estimated to be 1.73% in 2022–2023. Although this is very encouraging for Ladakh, lots of debates are there regarding the relevance of the NITI Aayog report as it is based on actual estimates of headcount ratio for 2005–2006, 2015–2016, and 2019–2020 from the National Family Health Surveys data, but interpolated for the year 2013–2014 and extrapolated for the year 2022–2023. Besides, Kargil district is selected for the study due to its distinct characteristics—(a) the entire district is the border region and mountainous with high altitudes of more than 4500 meters above the sea level; (b) it is one of the largest districts of India dominated by tribal people and about 88.40% of the population living in rural areas; (c) the region is extremely cold throughout the year with poor conditions of roadways, limited transport facilities etc.; (d) the district is vulnerable to landslides, cloudbursts, and flash floods; (d) the district is agriculture dominated with meagre land area availability for the purpose; (e) about 71.34% literacy as per Census 2011; (f) per capital income was Rs.15,269 in 2015 and current data is not available; (g) due to extreme cold conditions, health standard of people are not favourable for productive socio-economic outcomes; and (h) poor industrial development and the majority of people are engaged in the informal sector. All these indicate the likely presence of poverty in a multidimensional scale in the district. Further, this study has been conducted only at the household level although individual-level aspects of multidimensional poverty are more implicative. The primary reason is the lack of availability of all family members in the daytime when the survey was conducted. This constitutes a major limitation of the study which may be addressed in the future course of time. Despite this limitation, the study has important implications for similar regions in and outside the country.

This study has been conducted to observe the actual scenario of multidimensional poverty in Kargil at the ground level. By adopting the Alkire-Foster methodology and based on primary survey data of 315 households, it has been found that about 66.03% of rural households in Kargil are multidimensionally poor. It has been revealed that the fundamental causes of such a high rate of multidimensional poverty in Kargil include informal employment of people, indebtedness of households, unhygienic fuel for cooking, poor housing conditions, and lack of opportunities for health insurance and old age pensions in the region. The rest of the paper is organised as follows: Section 2 reviews the relevant literature; Section 3 describes the material and methods of the study; Section 4 analyses the data and discusses the results; and Section 5 concludes.

2. Literature review

Since alleviation of poverty is crucial for giving appropriate access to basic essentials of life of people such as food, clothes and shelter, and basic essentials of

households such as health, education, sanitation, electricity, clean fuel etc. studies are warranted for its proper conceptualization and measurement for framing suitable policy actions. The Goal-1 of Sustainable Development Goals (SDGs) also aims at poverty eradication in all its forms by 2030 for achieving sustainable development [3]. In this context, poverty needs to be conceptualised both at national and international levels, and should be measured both in monetary and multidimensional frameworks [4,5]. The concept of poverty in monetary terms—income or consumption expenditure—has been subjected to criticism based on the argument that the monetary aspect can't always truly be translated into the basic needs of people [6]. In this line of thought, poverty has been conceptualized as deprivations of people in health, education, standard of living, and in their socio-political status. Thus, the measurement of poverty is a multidimensional phenomenon, and it embraces two interpretations—(a) poverty is a deprivation in people's capabilities [7]; and (b) poverty is a counting measure of deprivation [8].

According to Amartya Sen, "poverty is not just a lack of money, it is not having the capability to realize one's full potential as a human being". Thus, human progress depends on the progress of human freedom and the capability of people to lead a decent life [9]. In other words, well-being should not be gauged in terms of money, but needs to be assessed through the functioning and capabilities of people. The World Bank also corroborates the thoughts of Amartya Sen that poverty is the deprivations in multiple aspects of the life of people which affect their well-being thereby making them incapable of accessing the basic necessities [10]. Accordingly, the concept of multidimensional poverty has been developed, and the removal of such poverty has become the pre-requisite for human development. This concept of poverty tries to capture human deprivations in multiple dimensions that are not directly measurable in monetary terms, and thus, measured by employing aggregate and household data [11]. These days estimation of this poverty has been proved useful for tracking the progress of national development goals, and SDGs.

It is observed by NITI Aayog that India has been successful in reducing multidimensional poverty from 29.17% in 2013–2014 to 11.28% in 2022–2023, i.e., about 24.82 crores of Indians have escaped poverty in this period [12]. It is also observed by the Aayog that about 5.94 crores of people have escaped from poverty in Uttar Pradesh during this period. Added to this crucial observation, a study found that multidimensional poverty has declined in Uttar Pradesh, but its rural concentration persisted [13]. Another study corroborates by stating that extreme poverty is primarily a rural issue [14].

The observation by the World Bank in 2013 was that globally "more than three-quarters of those living in extreme poverty are in rural areas and nearly two-thirds of the extremely poor earning a living from agriculture" [15]. In 2013, four out of every five persons living in rural areas were below the international poverty line of USD 1.90 per day [16]. As per the report of the UNDP[3]released in 2024, people in rural areas are poorer than people in urban areas, and about 28% of the global rural population is poor. In this line of observation, it is also found that a higher level of multidimensional poverty is among farming households [17]. Regarding the primary causes of multidimensional poverty in rural areas, it is observed that age of the household head, and education play a significant role [18]. Literature also notes the

critical role of deprivations of people in nutrition, asset ownership, sanitation, and cooking fuel in causing multidimensional poverty in the rural region [19]. Similarly, age of household head, family size, years of education, household expenditure, ownership of agricultural land, credit access, and access to safety nets have been found to be the key factors of multidimensional poverty in rural regions [20]. Also, larger family-size has been observed to increase the risk of households falling into multidimensional poverty in rural areas [21]. Further, the non-existence of land ownership, and food shortage have been evidenced to influence the incidence of poverty [22]. Despite these observations, there has been a significant decline in rural poverty over the last few years primarily due to the success of public policies which promote economic opportunities for rural people while enhancing their social safety and security [23]. Particularly, agriculture and rural development interventions have the potentials to reduce global multidimensional poverty by providing access to finance, training, and markets [24].

In the existing literature, most of the studies related to household-level multidimensional poverty consider health, education and standard of living dimensions of human well-being. However, in the Kargil district and also in the country context, other dimensions such as employment, women's empowerment, and social security are important in inferring the multidimensional aspects of poverty. In the Kargil district, due to limited industrialization, limited transportation facilities, and insufficient infrastructure development, people have limited choices in occupational domains. Similarly, the socio-economic empowerment of women in the district is also adversely affected due to limited opportunities and freedom available both in the household and society. Further, the availability and access to social safety nets are limited due to unfavourable topography, and lack of public awareness in the district. Hence, the current study is an attempt to include these three dimensions in addition to the standard dimensions of health, education and standard of living. Furthermore, this study is justified based on the prior observation that Kargil ranked last in the inter-district dimensions of socio-economic development in the erstwhile State of Jammu and Kashmir [25]. This study is an attempt to validate the observations by Mondal et al. [14], and that by Arora [13] that multidimensional poverty persists in rural areas. Especially, this study covers the rural region that has round-the-year harsh weather conditions, shares a sensitive border of the nation, mountainous landscape, tribal dominance, and agriculture-base. In this pre-text, this study examines the multidimensional aspects of rural households in the Kargil district of Ladakh based on a framework of people's deprivations in health, education, livelihood, living conditions, empowerment, and social security.

3. Materials and methods

The study adopted an exploratory empirical research design based on primary data to examine multidimensional aspects of poverty in the rural households of the Kargil district of Ladakh. Required data have been collected from 315 sample households through a field survey by administering a semi-structured interview schedule during 2021 and 2022 depending on suitable weather conditions. The sample households from the rural villages have been randomly selected following a

multi-stage sampling framework. *First*, the Kargil district of Ladakh has been conveniently chosen for the study. *Second*, seven blocks out of nine blocks of Kargil district have been randomly selected. These blocks are Kargil, Drass, Shargole, Shakar Chicktan, Taisuru, Gundmanglpur, and Sankoo blocks. *Third*, one village from each of these seven blocks has been randomly chosen by using the random number generation method. These villages are – Minjee village from the Kargil block; Muradbagh village from the Drass block; Skambo village from the Shargole block; Yogmakharbu village from the Shakar Chicktan; Achambur village from the Taisuru block; Gundmanglpur village from the Gundmanglpur block; and Thasgam village from the Sankoo block.

In this study, the sampling frame consists of a total of 1223 households in the seven selected villages which constitute the population in the study. Then using the Cochran sample size formula (Raosoft online sample size calculator) a total of 293 households was obtained as the minimum sample size at 95% confidence level. However, for better village-wise allocation of households, this minimum sample size has been increased to 315, and then the number of sample households in each village has been calculated proportionately. Thus, in the *fourth* step, 80 households from the Minjee village; 25 households from the Muradbagh village; 25 households from the Skambo village; 20 households from the Yogmakharbu village; 20 households from the Acgambur village; 65 households from the Gundmanglpur village; and 80 households from the Thasgam village have been randomly selected at 95% confidence level. The summary of this multi-stage sampling framework is presented in **Table 1**. This sampling design is free from biases to make the outcomes representative of the population.

Table 1. Multi-stage sampling framework.

Sample Blocks in Kargil	Total No. of Villages in Sample Blocks	Name of Sample Villages	Total No. of Households in Sample Villages	No. of Sample Households @ 95% confidence level
Kargil	22	Minjee	322	80
Drass	18	Muradbagh	89	25
Shargole	15	Skambo	96	25
Shakar Chicktan	11	Yogmakharbu	72	20
Taisuru	17	Achambur	64	20
Gundmanglpur	05	Gundmanglpur	257	65
Sankoo	14	Thasgam	323	80
Total			1223	315

Source: Authors' construction.

Alkire-Foster methodology [26] has been employed to measure multidimensional poverty in the region by calculating the Multidimensional Poverty Index (MPI). In this calculation, six dimensions have been used. These are: Education, health, standard of living, employment, women's empowerment, and social security. The selection of these dimensions has been made based on the literature and observations during the pilot study. The extant literature provides evidence in support of health, education, and standard of living as standard dimensions of MPI [26]. The field observations of household deprivations

concerning occupation type, women's socio-economic empowerment, and provision of social safety nets in the region justify the inclusion of employment, women's empowerment, and social security as three region-relevant dimensions of MPI.

In each dimension, certain relevant indicators have been taken. These are specified as follows: (i) In the education dimension, the indicators are years of schooling, child school attendance, and access to online education; (ii) in the health dimension, the indicators are child mortality, and nutrition; (iii) in the standard of living dimension, the indicators are electricity connection, sanitation quality, drinking water provision, flooring quality, cooking fuel, ownership of assets, and land holding; (iv) in the employment dimension, the indicators are formal employment, informal employment, and labour migration; (v) in the women's empowerment dimension, the indicators are female educational attainments, female economic empowerment, and female autonomy in the household; and (vi) in the social security dimension, the indicators are health insurance, old age pension, and government direct money transfer (transfer payments). Therefore, a total of 21 indicators in 6 dimensions of well-being have been considered in this study. The weightage of each of these dimensions is 1/6, and it is equally distributed between the indicators.

In the next step, the deprivation of a household in each indicator in a particular dimension has been defined. In the education dimension, a household is deprived if no member has completed 5-years of schooling, a school-aged child is not attending school upto age 13, and there is no access to online education at home. In the health dimension, the household is deprived if there is evidence of child mortality in the family in last one year, and any child or adult has nutritional information as malnourished. In the standard of living dimension, a household is deprived, if there is no electricity connection at home, sanitation quality is not good, no access to drinking water or available at 30-min walk, poor quality of flooring, unhygienic cooking fuel, poor asset ownership, and no land holding. In the employment dimension, a household is deprived if no member is employed in the formal and informal sectors, and no member is on migration due to job or income loss. In the women's empowerment dimension, a household is deprived if no female member has access to online education, no working-aged female member is engaged in economically productive activity, and no female member of age 15 or more has autonomy in consumption decisions. In the social security dimension, a household is deprived if no member has health insurance, no member is getting an old-age pension, and no member has received any transfer payments from the government.

The Alkire-Foster methodology provides techniques of calculating MPI based on the incidence and intensity of poverty. The former captures the percentage of households who are multidimensionally poor while the later infers about the percentage of deprivations of each household. The incidence of multidimensional poverty (also called headcount ratio) is given by H = q/n where q is the total number of multidimensionally poor households, and n is the total number of households. Similarly, the intensity of multidimensional poverty is given by $A = \frac{1}{q}\sum_1^q c_i$where $\sum_1^q c_i$is the sum of the proportion of total weighted deprivation that each household suffers, and q is the total number of multidimensionally poor households. Then, the

MPI is calculated by multiplying the scores of incidence and intensity of multidimensional poverty of a household. In the final step, a taxonomy of households based on the MPI scores has been prepared according to the following criteria: (i) If $0.50 \leq \text{MPI} \leq 1$, the household is under severe multidimensional poverty; (ii) if $0.33 \leq \text{MPI} < 0.50$, the household is under multidimensional poverty; (iii) if $0.20 \leq \text{MPI} < 0.33$, the household is vulnerable to multidimensional poverty; (iv) if $0 \leq \text{MPI} < 0.20$, the household is not multidimensionally poor.

In the final step, the significant determinants of the intensity of multidimensional poverty of households in the sample villages as well as in the Kargil district have been identified by estimating the following multiple regression model with robust standard errors.

$$MP_{hi} = \beta_1 Age + \beta_2 Faz_i + \beta_3 Fdx_i + \beta_4 Nfx_i + \beta_5 Dbt_i + \beta_6 Ced_i + \beta_7 Ldz_i + \varepsilon_i \quad (1)$$

Here, MP_{hi} stands for the intensity of multidimensional poverty of i^{th} rural household; *Age* is the age of the head of the household; *Faz* is the family size in the household; *Fdx* is the monthly food expenditure of the household; *Nfx* is the monthly non-food expenditure of the household; *Dbt* is the amount of debt standing in the household; *Ced* is the number of household members continuing their study; and *Ldz* is the size of agricultural land holding by the household.

In this approach, the covariates have been taken from the literature keeping in view their importance in determining multidimensional poverty in rural regions. The age of the household head, years of education, family size, household expenditure, credit access, and ownership of agricultural land have been empirically found to cause multidimensional poverty in rural regions [18–22]. However, in this study for better implications, household expenditure has been segregated into food and non-food expenditure, credit access has been replaced by out-standing household debt, and years of education has been replaced by a number of household members continuing their study to reflect life-long learning as it creates a current financial burden on the household.

Similarly, based on available literature and observations, it is hypothesized in this study that (i) the age of the household head, family size, and household debt determines the intensity of multidimensional poverty of households positively, and (ii) monthly food expenditure, monthly non-food expenditure, number of household members continuing their study, and size of agricultural land holding determine the intensity of multidimensional poverty of households negatively. The primary argument here is that the intensity of multidimensional poverty of rural households in the district can increase with the rise in the age of the household head, larger family size, and with increase in household debt. This argument justified the hypothesis stated at (i) above. Similarly, the intensity of multidimensional poverty of rural households in the district increases with a fall in the monthly food and non-food expenditures, a fall in the number of household members continuing their study, and size of agricultural land holding. This argument justified the hypothesis stated at (ii) above. It is proposed to test these hypotheses by estimating the econometric specification (1) by the Ordinary Least Square (OLS) method with robust standard

errors. Then, the estimated values of the coefficients are interpreted to draw relevant implications.

4. Results and discussion

At the outset, the extent of multidimensional poverty in the rural households of Kargil district has been calculated using the Alkire-Foster method, and the findings are summarized in **Table 2**. It is inferred that the incidence and intensity of multidimensional poverty in the Minjee village are 48.97% and 36.85% respectively. The MPI of this village is 0.180. It means on the average, households are not multidimensionally poor in this village.

Table 2. Extent of multidimensional poverty in rural households of Kargil.

Sample Villages In Kargil	No. of Sample Households	Incidence of Poverty or Headcount Ratio (H)	Intensity ofPoverty (A)	Village LevelMPI	Severity of Multidimensional Poverty
Minjee	80	48.97%	36.85%	0.180	Not Multidimensionally Poor
Muradbagh	25	60.00%	37.47%	0.225	Vulnerable to Multidimensional Poverty
Skambo	25	92.86%	39.14%	0.363	Multidimensionally Poor
Yogmakharbu	20	32.77%	36.20%	0.119	Not Multidimensionally Poor
Achambur	20	90.08%	39.09%	0.352	Multidimensionally Poor
Gundmanglpur	65	71.00%	38.70%	0.275	Vulnerable to Multidimensional Poverty
Thasgam	80	66.21%	37.84%	0.251	Vulnerable to Multidimensional Poverty

Source: Authors' calculation from primary data.

In the Muradbagh village, the incidence and intensity of multidimensional poverty are 60.0% and 37.47% respectively. The MPI of this village is 0.225. It means on average, households are vulnerable to multidimensional poverty in this village. In the Skambo village, the incidence and intensity of multidimensional poverty are 92.86% and 39.14% respectively. The MPI of this village is 0.363. It means on the average, households are multidimensionally poor in this village. In the Yogmakharbu village, the incidence and intensity of multidimensional poverty are 32.77% and 36.20% respectively. The MPI of this village is 0.119. It means on average, households are not multidimensionally poor in this village. In the Achambur village, the incidence and intensity of multidimensional poverty are 90.08% and 39.09% respectively. The MPI of this village is 0.352. It means on average, households are multidimensionally poor in this village. In the Gundmanglpur village, the incidence and intensity of multidimensional poverty are 71.0% and 38.7% respectively. The MPI of this village is 0.275. It means on average, households are vulnerable to multidimensional poverty in this village. In the Thasgam village, the incidence and intensity of multidimensional poverty are 66.21% and 37.84% respectively. The MPI of this village is 0.251. It means on the average, households are vulnerable to multidimensional poverty in this village.

In the next step, the exact number of rural households under multidimensional poverty in the sample villages of Kargil has been obtained, and summarized in **Table**

3. It is revealed that the total number of rural households under severe multidimensional poverty in the Kargil district is nominal, i.e., it is just 02 out of a total sample of 315 rural households. However, the total number of rural households under multidimensional poverty in the district is 208 out of a total sample of 315 rural households which is about 66.03%. This finding validates the observations that multidimensional poverty persists in rural areas, put ward in the studies by Mondal and others, and by Arora. Further, the total number of rural households vulnerable to multidimensional poverty in the district is 105 out of a total sample of 315 rural households which is about 33.33%.

Table 3. No. of rural households under multidimensional poverty in Kargil.

Sample Villages In Kargil	No. of Sample Households	Households under Severe Poverty	Households under Poverty	Households Vulnerable to Poverty
Minjee	80	01 (1.25%)	41 (51.25%)	38 (47.5%)
Muradbagh	25	-	16 (64.0%)	09 (36.0%)
Skambo	25	01 (4.0%)	22 (88.0%)	02 (8.0%)
Yogmakharbu	20	-	08 (40.0%)	12 (60.0%)
Achambur	20	-	18 (90.0%)	02 (10.0%)
Gundmanglpur	65	-	48 (73.85%)	17 (26.15)
Thasgam	80	-	55 (68.75%)	25 (31.25%)
Kargil District	315	02 (0.63%)	208 (66.03%)	105 (33.33%)

Source: Authors' calculation from primary data.

After understanding the extent of multidimensional poverty in the rural households of Kargil, the pattern of deprivation structure in each sample village under multidimensional poverty has been analysed. The outcomes are presented in **Table 4**. It is found that no village under the study is having deprivation in the health dimension. Thus, the health dimension has no contribution to multidimensional poverty. The highest percentage of deprivation has been noticed in the social security dimension thereby contributing to multidimensional poverty the most. The second highest deprivation has been observed in the employment dimension, and thus, its contribution to multidimensional poverty is also significant. The third highest deprivation has been observed in the women's empowerment dimension, and thus, its contribution to multidimensional poverty is noteworthy. Furthermore, the deprivations in education and standard of living dimensions are also important in contributing to the multidimensional poverty in the Kargil district. This implies that the policy-circle needs to focus on improving the performance of indicators in the employment, social security, and women's empowerment dimensions. However, it does not mean that other dimensions such as health, education, and standard of living should not be ignored. This means the policy interventions in these dimensions need moderate improvements for better performance. This will help rural households come out of their vulnerability to multidimensional poverty.

Table 4. Deprivation structure under multidimensional poverty in Kargil.

Sample Villages In Kargil	Health dimension (%)	Education dimension (%)	Standard of living dimension (%)	Employment dimension (%)	Social Security dimension (%)	Women's Empowerment dimension (%)
Minjee	0.00	6.82	4.78	29.04	44.28	15.08
Muradbagh	0.00	9.20	8.30	24.30	43.38	14.83
Skambo	0.00	10.52	7.70	23.52	42.58	15.68
Yogmakharbu	0.00	1.18	6.75	30.69	46.04	15.35
Achambur	0.00	13.43	7.43	24.12	40.42	14.60
Gundmanglpur	0.00	9.76	5.53	27.30	43.06	14.35
Thasgam	0.00	5.59	8.25	27.43	44.04	14.68

Source: Authors' calculation from primary data.

In the final step, factors determining the intensity of multidimensional poverty of households in the sample villages as well as in the district as a whole have been found by estimating the regression specification (1) using the OLS method with robust standard errors. But before the results of OLS estimation are generated, the descriptive statistics for each of the variables for sample villages and the Kargil district have been calculated (Please see Appendix). The summary statistics on Mean, Standard Deviation, Minimum and Maximum Observations have been calculated which indicate the presence of heterogeneity across sample villages. Thus, the intensity of multidimensional poverty seems to be differently affected by the covariates of the study. The results of OLS estimation are reported in **Table 5**.

It is noticed from **Table 5** that in the Minjee village, the intensity of multidimensional poverty of households is positively determined by the age of the head of the household at 5% level of significance; and by the family size at 1% level of significance, but negatively determined by the monthly non-food expenditure at 1% level of significance. *Second*, in the Thasgam village, the intensity of multidimensional poverty in households is positively influenced by the age of the head of the household, family size and household debt at 1% level of significance. *Third*, in the Gundmangalpur village, the intensity of multidimensional poverty of households is positively by the family size at 1% level of significance, and by the household at 10% level of significance. Besides, it is evidenced that the monthly food expenditure exerts a negative impact on the intensity of multidimensional poverty in households at 1% level of significance. *Fourth*, in the Muradbagh village, the intensity of multidimensional poverty of households is negatively determined by the monthly non-food expenditure at 1% level of significance. *Fifth*, in the Achambur village, the intensity of multidimensional poverty of households is positively determined by the family size at 1% level of significance, and by the non-food expenditure at 1% level of significance. *Sixth*, in the Skambo village, the intensity of multidimensional poverty of households is positively determined by the family size at 1%, and negatively by the household debt at 5% level of significance. *Seventh*, in the Yokamakharbu village, the intensity of multidimensional poverty of households is positively determined by the age of the household head and household debt at 1% and 5% levels of significance respectively. Besides, the intensity of

multidimensional poverty in this village is negatively determined by the size of land holding at 10% level of significance.

Table 5. Determinants of multidimensional poverty in rural households in Kargil.

Variables	Minjee	Thasgam	Gundmangalpur	Muradbagh	Achambur	Skambo	Yokmakharbu	Kargil District
Age	0.022**	0.031*	−0.003	0.027	0.004	−0.003	0.029*	0.020*
Faz	0.292*	0.335*	0.355*	−0.324	0.495*	0.397*	0.150	0.316*
Fdx	−0.00008	−0.0002	−0.0001*	0.0003	−0.0001	−0.0001	0.00003	−0.0002*
Nfx	−0.0001*	−0.0001	−0.00004	−0.00003*	−0.00002*	0.00005	−0.00007	−0.00003*
Dbt	0.0000003	0.0000009*	0.000001***	−0.000001	−0.00000005	−0.000002**	0.00009**	0.0000003
Ced	0.029	0.233	0.261	0.322	−0.108	0.065	−0.007	0.179**
Ldz	0.082	−0.210	0.712	−0.503	0.198	0.547	−1.422***	−0.227
Adj. R-sq.	0.58	0.73	0.75	0.60	0.93	0.95	0.69	0.70
R-Sq.	0.61	0.75	0.77	0.70	0.95	0.96	0.79	0.71
F-Stat.	15.56*	127.83*	30.40*	7.45*	218.26*	264.43*	8.91*	107.15*

Source: Authors' calculation; Note: *,**,***stand for significance at 1%, 5%, 10% levels respectively. Note on Description of Variables: Age—Age of the Head of the Household; Faz—Family Size; Fdx—Monthly Food Expenditure of the Household; Nfx—Monthly Non-food Expenditure of the Household; Dbt—Amount of Debt Standing in the Household; Ced—No. of Household Members Continuing Their Study; Ldz—Size of Agricultural Land Holding by the Household.

Last, for the Kargil district as a whole, it is evidenced that the intensity of multidimensional poverty of households is positively determined by the age of the household head and family size at 1% level of significance; and also positively by the number of household members continuing their study at 5% level of significance. But it is negatively determined by monthly food and non-food expenditures at 1% level of significance.

These results lend support to the hypothesis that the intensity of multidimensional poverty in households is positively determined by the age of the head of the household, particularly in the Minjee, Thasgam and Yokmakharbu villages, and also in the Kargil district as a whole. The hypothesis that the intensity of multidimensional poverty of households is positively determined by family size gets validated, particularly in Minjee, Thasgam, Gundmangalpur, Achambur and Skambo villages, and also in the Kargil district as a whole. The hypothesis that the intensity of multidimensional poverty of households is positively determined by the household debt gets validated, particularly in Thasgam, Gundmangalpur and Yokamakharbu villages. The hypothesis that the intensity of multidimensional poverty of households is negatively determined by the monthly food expenditure of households gets validated, in the Gundmangalpur village and also in the Kargil district as a whole. The hypothesis that the intensity of multidimensional poverty of households is negatively determined by the monthly non-food expenditure of households gets validated, particularly in Minjee, Muradbagh and Achambur villages, and also in the Kargil district as a whole. The hypothesis that the intensity of multidimensional poverty of households is negatively determined by the size of land holding of households gets validated, in the Yokmakharbu village. However, the results could not validate the hypothesis of the study that the number of

household members continuing their study negatively determines the intensity of multidimensional poverty of households in the Kargil district.

In the Minjee village, the intensity of multidimensional poverty is primarily determined by the higher age of household head, and larger family size; and elevated non-food expenditure is a contributing factor towards poverty reduction. In the Thasgam village, the intensity of multidimensional poverty is mainly due to the higher age of the household head, larger family size, and outstanding household debt. In the Gundmangalpur village, the intensity of multidimensional poverty is essentially due to larger family size, and outstanding household debt; and enhanced food expenditure is a contributing factor towards poverty reduction. In the Muradbagh village, higher non-food expenditure is a contributing factor towards poverty reduction. In the Achambur village, the intensity of multidimensional poverty is primarily due to larger family size, and larger non-food expenditure is a contributing factor towards poverty reduction. In the Skambo village, the intensity of multidimensional poverty is primarily due to larger family size. In the Yokmakharbu village, the intensity of multidimensional poverty is essentially due to the higher age of the household head and outstanding household debt, and the bigger size of agricultural land holding is a contributing factor towards poverty reduction.

In the Kargil district as a whole, the age of household head and family size are the most important contributing factors to multidimensional poverty, whereas household expenditure on food and non-food items helps reduce the intensity of poverty in the region. This finding corroborates the findings in the literature [27]. Particularly, the finding that family size increases poverty intensity is consistent with that of Anyanwu [28] and Meher et al. [19], but contradicts the findings of Roy et al. [29]. The possible reason may be that households with less number of economically engaged members are more likely to fall into multidimensional poverty due to increased family burden. Similarly, the finding that the age of household head increases poverty intensity is consistent with the findings of Bersisa and Heshmati [30]. The reason may be a decline in the capacity to earn and manage the household burden at a higher age. Further, the finding that an increase in household consumption expenditure reduces poverty intensity agrees with that of Eze and Alugbuo [31]. This finding also corroborates the findings of the Household Consumption Expenditure Survey[4] undertaken by the National Sample Survey Office, Government of India that elevated non-food expenditure in rural areas is the main cause of poverty reduction in India. Last, it is observed that an increase in the number of children in the household attending schools adds to the poverty intensity is supported by the findings of Zanbak and Cagatay [32].

5. Conclusions

In the *Amrit Kaal*, when India has already stepped forward to become *Viksit Bharat@2047*, it is quintessential to reduce poverty and inequality of any kind to their least possible levels for achieving the highest degree of human development with peace and happiness. In this context, the multidimensional aspects of poverty have been examined for the rural households in the Kargil district of Ladakh. The analysis of primary data collected from 315 sample households infers the presence of

multidimensional poverty in about 66.03% of households. It is further found that about 33.33% of households are vulnerable to multidimensional poverty. The key findings of the study reveal that social security, nature of employment, women empowerment, standard of living, and education dimensions play a critical role in contributing to the multidimensional poverty in the Kargil district.

Regarding the contributing factors of vulnerability to multidimensional poverty in the Kargil district, social security, nature of employment, women empowerment, and the standard of living of households play a determining role. In both the cases of multidimensional poverty and vulnerability to multidimensional poverty, the major contributing indicators to deprivations include lack of access to social security measures such as health insurance, dearth of economic empowerment of women, abundance of informal employment, poor housing, and unhygienic cooking fuel use. In the Kargil district, the benefits of social security schemes such as the Public Distribution System, Pradhanmantri Awas Yojna, Old Age Pension Scheme and Janani Suraksha Yojna may not be reaching the bottom of the pyramid [33]. Social security measures can directly impact health, education, employment and living standards [34]. These measures can also protect vulnerable households from economic shocks etc. [35]. Thus, careful monitoring and control in the implementation of social safety-net schemes in the Kargil district is required from the governmental point of view. Similarly, the employment status of households has been observed to influence families that are multidimensionally poor and also vulnerable to poverty because those employed in the formal sector have a better chance of escaping poverty [27,36]. In the Kargil district, people are mainly employed in the informal sector thereby exposed to economic shocks and multidimensional poverty. Thus, it is important to deepen education and skill development to increase the penetration of formal employment among households. Furthermore, women's empowerment has an important influence on the health, education, employment, decision-making, and overall well-being of a household [37–39]. It is observed that the lack of proper empowerment of women in the Kargil district is a significant cause of multidimensional poverty. Thus, increased women's access to education, employment and self-employment, and autonomy in decision-making can significantly reduce multidimensional poverty in the district.

Moreover, in the Kargil district living standard of households as measured by the extent of electricity connection, sanitation quality, drinking water provision, flooring quality, cooking fuel, ownership of assets, and land holding contribute to multidimensional poverty. The primary reason is the limited access to socio-economic opportunities such as good healthcare, quality education, and decent employment [40]. Hence, the implication is that the policy-circle needs to focus on improving these aspects of well-being for fostering decent living, and achieving enhanced human development in the region. It is important to improve the conditions for better health outcomes and educational attainments in the region. Based on the findings of the study, the economic implication is that the intensity of multidimensional poverty of households in the Kargil district can be reduced by ensuring better healthcare, quality and skill-based education, improved standard of living, formal employment and assured social security outcomes of household members by catalysing available demographic dividend, land holding, foods habits

of people, and availability of agricultural land holding. Despite the elegancy of the study, its scope and depth are limited. The important limitations of the study are: Non-consideration of individual-level multidimensional aspects of poverty, non-coverage of the entire Ladakh region, non-inclusion of other aspects of the socio-economic profile of households such as remittances, savings, dependency ratio, financial inclusion etc. which have bearings on human well-being. Therefore, the study can be extended to include other dimensions of well-being such as banking habits of people, dependency ratio etc. for a better picture of multidimensional poverty. The study can also be extended to analyse individual level poverty status in the district.

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Notes

[1] https://www.niti.gov.in/sites/default/files/2024-01/MPI-22_NITI-Aayog20254.pdf.
[2] https://www.niti.gov.in/sites/default/files/2024-01/MPI-22_NITI-Aayog20254.pdf.
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Appendix

Table A1. Descriptive statistics of variables for sample villages & Kargil district.

Variables	Minjee	Thasgam	Gundmangalpur	Muradbagh	Achambur	Skambo	Yokmakharbu	Kargil District
MP_{hi}	Mean: 1.31 S.D.: 1.43 Min.:0.0 Max.:5.23 N: 80	Mean: 2.04 S.D.: 1.85 Min.:0.0 Max.:7.2 N:80	Mean:1.8 S.D.: 1.5 Min.:0.0 Max.:6.2 N: 65	Mean: 1.62 S.D.: 1.33 Min.:0.0 Max.:3.5 N:25	Mean:2.13 S.D.: 1.26 Min.:0.0 Max.:4.3 N:20	Mean:2.24 S.D.: 1.30 Min.:0.0 Max.:6.2 N:25	Mean: 0.71 S.D.: 1.00 Min.: 0.0 Max.:3.4 N:20	Mean:1.72 S.D.: 1.57 Min.:0.0 Max.:7.2 N: 315
Age	Mean: 57.9 S.D.: 12.1 Min.:35.0 Max.:88 N:80	Mean: 53.7 S.D.: 9.7 Min.:28 Max.:72 N:80	Mean:52.4 S.D.: 12.9 Min.:28 Max.:85 N:65	Mean:54.1 S.D.: 14.6 Min.:23.0 Max.:80.0 N:25	Mean:62.0 S.D.: 16.5 Min.:40 Max.:90 N:20	Mean:55.9 S.D.: 14.5 Min.:30.0 Max.:85,.0 N:25	Mean:55.4 S.D.: 10.9 Min.:35.0 Max.:80.0 N:20	Mean: 55.3 S.D.: 12.6 Min.: 23 Max.: 90 N: 315
Faz	Mean: 7.3 S.D.: 2.5 Min.: 3.0 Max.:14.0 N: 80	Mean: 8.2 S.D.: 3.7 Min.:4.0 Max.:19.0 N:80	Mean:6.6 S.D.: 3.02 Min.:2.0 Max.:16.0 N:65	Mean:7.2 S.D.: 2.8 Min.:3.0 Max.:14.0 N:25	Mean:6.1 S.D.: 2.8 Min.:3.0 Max.:13.0 N:20	Mean:6.2 S.D.: 2.7 Min.:2.0 Max.:15.0 N:25	Mean:5.9 S.D.: 2.2 Min.:3.0 Max.:11.0 N:20	Mean: 7.11 S.D.: 3.1 Min.:2.0 Max.:19.0 N: 315
Fdx	Mean: 9275 S.D.: 4182.5 Min.:3000 Max.:20,000 N:80	Mean:8375 S.D.: 2582.2 Min.:4000 Max.:15,000 N:80	Mean:7461.5 S.D.: 3400.7 Min.:2500 Max.:15,000 N:65	Mean:8240 S.D.: 2350.2 Min.:4000 Max.:13,000 N:25	Mean:6325 S.D.: 3001.2 Min.:3000 Max.:15,000 N:20	Mean:6240 S.D.: 1774.4 Min.:3000 Max.:11,000 N:25	Mean: 7760 S.D.: 2912.3 Min.:4000 Max.:15,000 N:20	Mean:8065.7 S.D.: 3331.1 Min.: 2500 Max.:20,000 N: 315
Nfx.	Mean: 13,169 S.D.: 6126.3 Min.:4000 Max.:27,000 N:80	Mean:12,025 S.D.: 4304.8 Min.:5000 Max.:20,000 N:80	Mean:12,669 S.D.: 8019.6 Min.:2000 Max.:50,000 N:65	Mean:16,800 S.D.: 19,166 Min.:4000 Max.:105,000 N:	Mean:15,500 S.D.: 20,940 Min.:3000 Max.:100,000 N:20	Mean: 8100 S.D.: 3763.9 Min.:2500 Max.:17,000 N:25	Mean:18,238 S.D.: 9366.8 Min.:7000 Max.:40,950 N:20	Mean: 13,131 S.D.: 9678.6 Min.: 2000 Max.:105,000 N: 315
Dbt	Mean:50,963 S.D.: 229,040 Min.:0.00 Max.:1,900,000 N:80	Mean:33,725 S.D.: 196,890 Min.:0.00 Max.:1,700,000 N:80	Mean:32,631 S.D.: 79,977.0 Min.:0.0 Max.:500,000 N:65	Mean:92,000 S.D.: 263,150 Min.:0.0 Max.:1,200,000 N:25	Mean:29,900 S.D.: 53,927 Min.:0.0 Max.:200,000 N:20	Mean:52,280 S.D.: 129,570 Min.:0.0 Max.:600,000 N:25	Mean:1500 S.D.: 3663.5 Min.:0.0 Max.:10,000 N:20	Mean: 41,686 S.D.: 177,160 Min.:0.0 Max.:1,900,000 N: 315
Ced	Mean: 2.4 S.D.: 1.3 Min.:0.0 Max.:6.0 N:80	Mean:2.9 S.D.: 1.3 Min.:1.0 Max.:8.0 N:80	Mean:2.5 S.D.: 1.7 Min.:0.0 Max.:7.0 N:65	Mean:2.9 S.D.: 1.6 Min.:0.0 Max.:6.0 N:25	Mean: 1.9 S.D.: 1.04 Min.:1.0 Max.:5.0 N:20	Mean:2.4 S.D.: 1.2 Min.:0.0 Max.:6.0 N:25	Mean:2.3 S.D.: 1.3 Min.:0.0 Max.:4.0 N:20	Mean: 2.6 S.D.: 1.4 Min.: 0.0 Max.:8.0 N: 315
Ldz	Mean:0.73 S.D.: 0.22 Min.:0.4 Max.:2.0 N:80	Mean:0.88 S.D.: 0.36 Min.:0.0 Max.:2.0 N:80	Mean:0.66 S.D.: 0.15 Min.:0.0 Max.:1.0 N:65	Mean:0.64 S.D.: 0.14 Min.:0.4 Max.:1.0 N:25	Mean:0.68 S.D.: 0.16 Min.:0.5 Max.:1.0 N:20	Mean:0.55 S.D.: 0.14 Min.:0.30 Max.:1.0 N:25	Mean:0.63 S.D.: 0.28 Min.:0.0 Max.:1.0 N:20	Mean: 0.72 S.D.: 0.26 Min.: 0.0 Max.: 2.0 N: 315

Source: Authors' calculation; Note on Description of Variables: MP_{hi}—Intensity of Multidimensional Poverty; Age—Age of the Head of the Household; Faz—Family Size; Fdx—Monthly Food Expenditure of the Household; Nfx—Monthly Non-food Expenditure of the Household; Dbt—Amount of Debt Standing in the Household; Ced—No. of Household Members Continuing Their Study; Ldz—Size of Agricultural Land Holding by the Household.

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Article

Anthropocene futures: Regeneration as a decarbonization strategy

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Abstract: In the context of the Anthropocene, and in the face of an unprecedented climate crisis generating 20 billion tonnes of CO_2 annually, this study critically examines the transition from a 'grey' economy based on fossil fuels to a 'green' and regenerative economy, proposing two interrelated strategies: the transformation of terrestrial and agricultural systems to enhance natural carbon sequestration (including halting deforestation, regenerative agriculture and sustainable livestock systems), and the restructuring of global social metabolism (promoting reduced consumption, circular economies and renewable energy). The analysis emphasizes that this transition will require unprecedented global cooperation and bold government policies and will face significant challenges such as resistance from entrenched interests and global inequalities; however, the expected benefits—including a stable climate, healthy ecosystems and a sustainable economy—justify the necessary efforts, framing this transformation not just as a technical challenge but as an ethical and ontological imperative to move from an extractive relationship with the planet to a co-creative role that ensures intergenerational prosperity and planetary health.

Keywords: green economy; zero-net; carbon; sustainability; development

1. Introduction

This study critically examines how the transition to a regenerative economy can accelerate the process of global decarbonization in the era of human dominance. This era, also known as the Anthropocene and considered by many experts to be a new geological epoch, represents a turning point in Earth's history. It is characterized by the impact of human activity in shaping the future of the planet. Anthropogenic actions have now decisively influenced Earth's systems, altering natural processes and leaving an indelible mark on the geological record [1–4], driven primarily by exponential human population growth and rising per capita consumption [5], factors operating in a context of unprecedented global hyper-connectivity [6,7]; This interconnectedness, facilitated by information and communication technologies, has not only transformed economic dynamics, but has permeated all spheres of human activity and its interaction with the natural environment, reconfiguring economic, cultural, political, ecological and social aspects on a planetary scale [8,9]. The biosphere is at the epicenter of this convergence of transformative forces and is experiencing abrupt and potentially irreversible changes in global ecological systems [10,11], manifested in accelerated biodiversity loss, changes in global climate patterns, disruptions in fundamental biogeochemical cycles, and widespread land degradation and expansion of drylands.

The Earth's evolution is being reconfigured in the face of humanity. Humanity's insatiable appetite for progress is eroding the planet's biosphere, pushing it beyond its regenerative limits [12,13]. This onslaught is manifesting itself in a three-act tragedy:

First, the overexploitation of renewable sources of life; second, the depletion of Earth's finite resources; and third, the erosion of ecosystem resilience. As we push against these planetary boundaries, we find ourselves in a race against time, challenged to redefine our relationship with the only stage we have ever known: Earth.

Current projections show a worrying outlook for the near future. If current trends in population growth and consumption patterns continue unchecked, human demand for resources and ecosystem services is projected to exceed the planet's regenerative capacity by 100% by 2050. The pressure on natural resources goes beyond the extraction of raw materials. It also affects the ability of ecosystems to absorb the waste we produce, a crucial process for sustaining modern lifestyles [14]. Without nature's capacity to regenerate, our consumption patterns would become unsustainable in the long run, accelerating the ecological collapse that threatens both the natural environment and the societies that depend on it [15], a perspective that underscores the urgency of implementing radical transformations in our economic, technological and social systems; developing and deploying clean technologies; promoting green lifestyles; intensifying conservation and ecological restoration efforts; and strengthening global environmental governance mechanisms. This era therefore represents both an unprecedented challenge and a unique opportunity to redirect the course of human civilization towards a sustainable and equitable future, requiring a deep understanding of the interconnectedness of Earth systems that must catalyze a radical transformation in our relationship with the world, guided by the principles of sustainability, equity and respect for planetary boundaries.

A global paradox is unfolding with intensity: while science urgently calls for a reduction in emissions of climate-changing gases, especially carbon dioxide (CO_2), society is at an ideological crossroads. For decades, the Intergovernmental Panel on Climate Change (IPCC) has warned of a bleak future. But this scientific urgency is colliding with skepticism and short-term economic priorities. At the heart of this controversy is a key question: Are CO_2 levels a valid indicator of societal progress? This debate divides nations, particularly in countries such as the United States, where environmental sustainability is often overshadowed by economic growth [16]. The reluctance to prioritize CO_2 reduction over immediate economic interests reflects not only political myopia, but also the deep contradictions in our development model. As the world approaches a climate tipping point, reconciling progress and sustainability has never been more urgent or challenging [17]. This attitude reflects a dichotomy in global perceptions of decarbonization: while some countries see it as an opportunity for sustainable development, others see it as a threat to their economic growth [18,19].

The reluctance of the United States to fully commit to global decarbonization targets is deeply rooted in the capitalist development model that underpins the global economy. This model, which prioritizes endless profit generation, finds its strongest advocate in the U.S. From this perspective, economic interests often outweigh the urgent need for environmental action. International alliances forged by the US tend to be driven by common interests rather than principles of reciprocity. This economic-centric approach helps explain the country's reluctance to take decisive action to address the climate crisis at this critical juncture in history [17].

Despite these political and economic challenges, scientific projections underline the seriousness of the situation. According to Lashitew and Mu [17], even with the

implementation of effective mitigation policies and the development of emission-negative technologies [20], global warming is likely to exceed 3 ℃ by the end of the 21st century. This scenario underscores the urgency of a paradigm shift in development thinking and the need for a robust global commitment to decarbonization that transcends short-term national interests in favor of long-term planetary sustainability.

On the cusp of an unprecedented climate crisis, humanity stands at a crucial crossroads that requires a radical transformation of our economic and social systems, moving from a "grey" economy based on fossil fuels and unsustainable practices to a "green" and regenerative economy, a transition that is not merely an option but an imperative necessity to ensure the survival and prosperity of future generations, offering a hopeful vision of a sustainable future amidst increasingly alarming climate projections that underscore the urgency of taking drastic action to reduce carbon emissions [21].

A regenerative economy, unlike the current extractive model, seeks not only to minimize environmental damage but also to restore and regenerate ecosystems, based on fundamental principles such as circularity, which aims to design production and consumption systems that eliminate the concept of 'waste' by mimicking the closed cycles of nature; biomimicry, which draws on natural processes to develop efficient and sustainable technologies and systems; a complete transition to clean and renewable energy sources; and, last but not least, a sustainable development policy, which is based on the principles of subsidiarity and proportionality.

The adoption of this regenerative economic model promises to accelerate the decarbonization process through several interlinked pathways [22]: First, clean energy innovation, driven by massive investment in renewable energy technologies, not only reduces direct emissions but also catalyses a virtuous circle of innovation that makes these technologies increasingly efficient and affordable, while decentralising energy production through microgrids and community energy systems can further accelerate this energy transition; second, industrial transformation, through the adoption of circular economy principles, can significantly reduce emissions associated with raw material extraction and waste management, revolutionising production processes with technologies such as additive manufacturing (3D printing) and the development of new biodegradable materials; third, regenerative agriculture, including practices such as agroforestry and holistic grazing management, not only reduces emissions associated with industrial agriculture, but also sequesters carbon in the soil, transforming agricultural fields from emission sources to carbon sinks; fourth, reinventing transport systems by prioritising electric public transport, active mobility and zero emission vehicles can reduce emissions from the transport sector, one of the largest contributors to climate change; and fifth, implementing sustainable building techniques and policies and energy retrofits in existing buildings not only reduces operational emissions, but also addresses the emissions embodied in building materials.

In order to achieve the proposed objective of this study, a qualitative approach was adopted, using documentary analysis as the main investigative tool. The research methodology was designed to ensure both depth and breadth in understanding the interrelationships between the Anthropocene and decarbonization processes in the

contemporary global context [23]. The bibliographic search strategy was systematically structured around three interrelated thematic axes: the concept of the Anthropocene and its implications, decarbonization processes and strategies, and the dynamic interrelationship between these two phenomena. This framework allowed for a comprehensive exploration of how the Anthropocene has influenced the context of decarbonization and its far-reaching global consequences. The search process was guided by selected keywords covering the full range of relevant concepts, including "Anthropocene", "decarbonisation", "grey economy", "green economy", "regenerative economy", "climate change" and "public policy".

To ensure a comprehensive and up-to-date review, the research drew on a range of high-quality sources. The main academic databases consulted included Wiley, SpringerLink, Elsevier, MDPI and BMC, which provided access to a wide range of academic materials, including peer-reviewed articles, academic books and book chapters. In addition, to incorporate practical policy perspectives, the study included an extensive review of reports and policy documents from relevant international organizations, accessed through their official platforms.

The documentary analysis process was rigorous, involving an initial review of 120 documents, of which 93 were finally selected on the basis of their relevance, quality and significant contribution to the research objective. These selected documents were systematically categorized into three main thematic groups: i) Conceptualization and implications of the Anthropocene (32 documents): This category focused on theoretical foundations, environmental and social implications, and historical development of the Anthropocene concept; ii) decarbonization processes and strategies (38 documents): These materials covered technical and technological aspects, policy frameworks, implementation strategies and economic implications of decarbonization efforts; and iii) systemic analysis and integration (23 documents): This group focused on the links between the Anthropocene and decarbonization, future scenarios and policy recommendations.

The research process, conducted over six months from February to July 2024, allowed for a detailed and reflective examination of the literature. This extended period facilitated the identification of patterns, emerging trends and key findings that underpin the study's conclusions. The systematic approach enabled an understanding of the interactions between the Anthropocene and decarbonization processes, revealing critical perspectives on their mutual influence and implications for current and future global environmental governance. The approach adopted not only facilitated the identification of current knowledge and gaps in the field [24], but also allowed for the development of new perspectives on the complex relationship between the Anthropocene and global decarbonization efforts.

2. Problematisation around the Anthropocene and decarbonisation

In this study, problematization is understood as a process in which an idea, situation or concept that is generally taken for granted is critically examined in order to reveal its underlying complexity and to challenge established assumptions. This approach, mainly used in academic and philosophical contexts, does not necessarily

seek to solve a problem, but rather to understand it in its full depth, taking into account multiple perspectives and uncovering hidden power relations.

The Anthropocene is emerging as a political concept, coined to draw attention to the scale of anthropogenic impact on a planetary scale. This term not only highlights physical changes in the global environment, but also raises fundamental questions about human agency and ethical responsibility in the context of contemporary life [25]. This phenomenon did not emerge as a result of deliberate planning, but rather as an unforeseen consequence of the industrialization of human societies [26]. This marks a crucial shift in the dynamics between humanity and the Earth system. Throughout history, meaningful human engagement with the geological forces of the planet has occurred only on a few exceptional occasions. Among these rare examples, the Montreal Protocol stands out as the most cited case [27], demonstrating the potential for coordinated global action to mitigate anthropogenic impacts on systems. This precedent underscores the possibility of positive human intervention on a global scale, offering a glimmer of hope in the context of contemporary environmental challenges.

In this framework of the Anthropocene, a sustainable development perspective is presented as an imperative that goes beyond conventional policies and requires a profound social transformation. In this context, the concept of agency becomes crucial and emerges as the central axis for catalyzing and implementing the necessary transformations. These transformations are aimed not only at limiting global warming to manageable levels, but also at achieving the wide range of goals set out in the SDGs, from eradicating poverty to preserving ecosystems. In this sense, the notion of agency goes beyond the mere capacity for individual or institutional action. It implies a reconceptualization of collective responsibility and global governance that recognizes socio-ecological systems [28]. This holistic approach is fundamental to addressing the complexity of the challenges of the Anthropocene, which require unprecedented cooperation across nations, sectors and disciplines.

Humanity's ability to influence the biosphere is redefining the limits of its existence. This global human agency manifests itself in heterogeneous ways that vary considerably across individuals and social groups, adding to the complexity of managing its impacts and potential. Otto et al. [29] argue that in order to achieve efficient resource use and sustainable ecosystem management—whether global, regional or local—it is imperative to intervene and improve existing social institutions. While it is undeniable that social institutions undergo renewal throughout history, the assumption that these changes can be directed or imposed by external agents can be questioned. The dynamics of institutional change often emanate from the very social groups that constitute and sustain them, responding to their changing needs, values and aspirations.

This critical inquiry examines the multifaceted nature of human agency within the global decarbonization paradigm, exploring its latent potential and inherent constraints. It aims to cultivate a more comprehensive understanding of global metamorphosis, acknowledging the intricate web of interconnections that drive this transformative process. By examining humanity's collective capacity to shape planetary outcomes, the analysis seeks to bridge theoretical abstractions with pragmatic implementations, thereby enriching the discourse on anthropogenic influence in the Anthropocene era. Under this premise, it is argued that to generate

adequate problematizations of decarbonization, it is essential to adopt a social-ecological systems perspective. This approach recognizes the complex interdependencies between human and natural systems and allows for a holistic and nuanced view of the challenges and opportunities presented by the transition to a regenerative society [30]. Linkages require addressing both sociopolitical challenges and ecological limits [31]. The relationship between socio-political problems—such as socio-economic inequality, resource conflicts, weak governance, unsustainable economic development models, environmental injustice, nationalism, populism and resistance to change—and ecological constraints—such as climate change, biodiversity loss, water scarcity, soil degradation and pollution—is undeniable. Social problems such as inequality and conflict are intertwined with environmental crises such as climate change and resource scarcity [31]. The current development model, focused on unlimited growth and intensive exploitation, has exacerbated these problems, disproportionately affecting vulnerable communities. Achieving a sustainable future requires a comprehensive approach that combines social equity with environmental sustainability. This means adopting an equitable development model, strengthening environmental governance, investing in renewable energy and promoting international cooperation. In this context, decarbonization is essential to mitigate climate change and ensure a fair and equitable future for all.

Applying a social-ecological lens to decarbonization analysis requires recognition of the complex interactions between social, economic and environmental spheres. This approach requires recognition of the multiple temporal and spatial dimensions within which these systems operate while identifying critical nodes where strategic interventions can have maximum impact. It is imperative to anticipate the potential spillover effects of policy implementation and to promote adaptive, flexible strategies for managing global change. Recognizing the close relationship between sociopolitical challenges and ecological limits, we can better anticipate cascading effects across scales and sectors. This approach not only illuminates the complexity of decarbonization efforts, but also highlights the delicate balance between human ingenuity and ecological constraints in shaping our future. Decarbonization as a global imperative requires not only technological innovation and bold public policies, but also a deep understanding of the socio-ecological dynamics that underpin our production and consumption systems.

Throughout the millennia of human history, our species has been inextricably intertwined with the natural world. From the earliest hunter-gatherers relying on the bounty of the land for sustenance to modern conservationists striving to protect the Earth's fragile ecosystems, humanity's relationship with nature has been a constant thread in our collective history. However, with the advance of civilization, population growth and technological development, this relationship has gradually turned into a dynamic of exploitation and degradation of the natural environment. The ecological footprint, as introduced by Wackernagel [32], provides a sophisticated framework for measuring the impact of human activities on ecosystems. This approach shows that virtually all daily activities—from bathing, eating, commuting, working and studying—contribute to the emission of CO_2, thereby exacerbating the climate crisis.

In this sense, significantly reducing CO_2 concentrations is a challenge that goes beyond simple technical or legislative adjustments. It would require a radical change

in the lifestyles of modern societies [33], a profound change in the status quo that governs our forms of production and consumption [33]. The reality, however, is that most people are unwilling to make such profound changes. Despite awareness of the destructive implications of the current model of development and the social metabolism that sustains it [33], contemporary societies tend to prioritize comfort, consumption and economic growth over environmental sustainability.

The discussion of decarbonization as a pathway to sustainable development is proving to be utopian under current societal metabolic conditions [33]. The scale of change required to achieve real decarbonization goes beyond mere technology or public policy, as it affects the very foundations on which our economies and lifestyles are built. Without a profound restructuring of the global socio-economic system and a fundamental rethinking of human priorities, decarbonization remains an unattainable goal under current circumstances. This phenomenon was first observed by William Stanley Jevons in the 1860s in his studies of coal consumption. His studies documented how savings from efficiency gains in industrial operations were reinvested in ways that expanded overall production, resulting in increased coal use. This dynamic came to be known as the Jevons Paradox [34]. Only through radical rethinking and transformative collective action will it be possible to build a future where development is not in constant conflict with the planet's ecological limits.

3. Anthropocene

The precise onset of the Anthropocene remains a matter of considerable debate. However, environmental changes associated with atmospheric gas fluctuations provide geological markers that are synchronous and globally distributed, allowing their identification on annual to decadal time scales. These markers are fundamental to establishing the Global Stratigraphic Boundary Point (GSSP) of the Anthropocene. The first proposed GSSP marker is a marked change in atmospheric methane levels more than 5000 years ago, although the lack of additional stratigraphic correlations precludes a definitive conclusion [35].

Two main dates have been proposed for the start of the Anthropocene. According to Lewis and Maslin [26], the first is 1610 and the second is 1964. The choice of 1610 attributes the beginning of this new geological epoch to the effects of the conquest of the Americas, trade routes and the rise of coal burning. This perspective highlights social issues such as the unequal power dynamics between different societies, the consequences of economic expansion and the globalization of trade, while underlining humanity's increasing dependence on fossil fuels. The European conquest of the Americas is cited as an important example of how human activities can set in motion large-scale processes that are difficult to predict. Instead, the 1964 selection shifts the narrative to an era of elite-driven technological advances that have threatened the sustainability of the planet. The development of military technology, from spears to nuclear weapons, highlights the concept of "progress traps", where technological advances do not always guarantee long-term benefits. The progress trap is an economic and social phenomenon in which technological and productivity advances paradoxically do not always translate into substantial improvements in quality of life or overall well-being. This concept suggests that progress can have side effects such

as increased expectations, increased competition, rapid obsolescence of skills and inequality in the distribution of benefits. In essence, it argues that economic and technological development should be evaluated not only in terms of growth or efficiency, but also by considering its holistic impact on society and human welfare [36].

The concept of the Anthropocene encompasses unprecedented, planet-wide changes driven by social transformations. It highlights the underlying social forces responsible for global change and reveals the tensions between generalized narratives of human impact and interpretations rooted in specific historical, political and cultural contexts [37]. These contrasts reflect the complexity of understanding and addressing human impacts on the planet and underline the need for multidimensional approaches to meet the challenges of the current era. The Earth system is an intricate web of interconnected components, each influencing the others in a dynamic of interactions [38]. This complex socio-ecological system comprises physical, chemical, biological and social elements that shape the current state and future trajectory of the planet. The four main components of the Earth system—atmosphere, biosphere, hydrosphere and geosphere—interact synergistically to regulate the functioning of the planet [39]. These components provide essential services such as climate regulation, food production and the provision of natural resources. For example, the climate system regulates temperature, precipitation and atmospheric circulation, while the biosphere provides ecological services such as nutrient cycling and biodiversity [40–45]. The complexity of the Earth system results from the multiplicity of processes operating at different scales and levels of organization [8]. Humans, as an integral part of this system, constantly interact with and influence these components. These interactions can lead to adaptive processes, change and, in many cases, uncertainty about the future of the system. The ability of humans to alter these natural components highlights the importance of understanding the system, where any action on one component can have unpredictable consequences on the rest, affecting both the balance of the planet and the well-being of its inhabitants.

The burgeoning global population, combined with prevailing patterns of consumption, has been the driving force behind the profound and rapid changes facing the planet today [6]. Globally, these changes are having a devastating impact on various aspects of the natural and social environment. One of the main impacts is accelerated deforestation, a process that is rapidly reducing forest cover in many regions of the world, affecting both ecosystems and the communities that depend on them [46]. This is compounded by the intensive use of agrochemicals, which not only degrades soils and pollutes water sources, but also seriously affects the health of the animal, plant and human species that inhabit these areas [47]. Another major consequence of these global changes is the loss of biodiversity. Species are disappearing at an unprecedented rate, altering ecosystems and disrupting the ecological balances that are fundamental to the functioning of the planet [48]. At the same time, we are witnessing a growing loss of ancestral knowledge, the knowledge accumulated over generations that has enabled indigenous cultures to live in harmony with nature. Modernization and globalization have eroded this knowledge, replacing it with technologies and practices that are more efficient in the short term, but unsustainable in the long term [49]. In addition, conflicts and wars, often linked to

access to increasingly scarce natural resources, have intensified in various parts of the world, exacerbating humanitarian and environmental crises [50]. The continued overuse of fossil fuels remains a major contributor to climate change, releasing huge amounts of greenhouse gases that exacerbate global warming [51]. This is compounded by land-use change, where natural areas and agricultural land are constantly being converted into urban and industrial areas, fragmenting habitats and further affecting ecosystems [52].

In this context, the Anthropocene emerges as a reflection of this new human-dominated geological epoch. Today, this epoch is characterized by the global environmental crisis, which is not limited to a single aspect but encompasses a wide range of interconnected problems. The globalized world is immersed in a market logic that prioritizes economic growth over environmental sustainability. This economic model has absorbed and subsumed the natural world, treating it as an infinite resource to be exploited without regard for the long-term consequences. A global society governed by parametric rationality, a logic based on the optimization of economic parameters that seeks to maximize efficiency and growth within a framework that largely ignores environmental limits [53]. This narrow focus on indicators such as GDP, production rates and consumption overlooks critical measures of environmental well-being, ecosystem health and social equity. The balance between human development and planetary sustainability has thus been profoundly altered, creating a crisis that requires an urgent overhaul of our economic, social and environmental systems to avoid even greater collapse in the future.

The above scenario underlines the need to change the way humanity interacts with the planet, to rethink the social metabolism. The Anthropocene, together with its wide interdisciplinary circulation, has generated a diversity of narratives about global change and possible futures [54]. The term has allowed discourses to emerge that range from deeply disturbing visions to hopeful perspectives. The focus on human agency has shifted from predominantly catastrophic narratives of global environmental change to new, empowering stories of action. This shift is based on the recognition that societies, which are now more globally interconnected, have the potential to decisively influence the Earth system. Despite the uneven contributions of different societies to global change, and the disproportionate benefits that certain regions or groups derive from Earth system changes, the Anthropocene highlights the growing interconnectedness of individuals and societies [55]. This global interconnectedness has given humanity a significant and growing influence within Earth system processes [38].

The narratives of the Anthropocene reflect a diverse panorama of approaches that, far from being limited to categorizing the phenomenon, seek to rethink the future and its interactions in a context of global innovation and transformation [38,56]. From a naturalistic perspective, science and technology are presented as fundamental tools for managing environmental change [8], while the post-nature narrative reconfigures the relationship between culture and the environment, blurring their traditional boundaries and suggesting a future in which coexistence is reinvented [57,58]. The eco-catastrophe narrative, in turn, confronts us with the risks of inaction in the face of possible collapse and highlights the ambivalent power of innovation to both alleviate and exacerbate crises [59]. Finally, the eco-Marxist vision profoundly challenges the

dynamics of capitalism that perpetuate resource exploitation and promote inequality, suggesting that any move towards true sustainability must address and transform current economic structures [60,61]. These narratives represent the complexity of the Anthropocene and project radically different futures where innovation becomes the linchpin of survival or collapse. In this context, new narratives need to be rethought to guide new processes of restoration and improvement of natural and social systems [62–64].

The emerging narrative on the Anthropocene must move beyond conventional typologies to an approach that not only acknowledges the magnitude of anthropogenic change, but also embraces the idea of "technological co-evolution" between natural and human systems. In this vision, humanity is no longer merely an agent of environmental disruption, but part of a dynamic web of interdependence in which technology and biology are intertwined in unprecedented ways. The future cannot be seen as a mere extension of today's problems, but as a space for the creation of a new planetary pact in which the boundaries between the natural, the artificial and the human dissolve in awareness and cooperation. Here, innovation is not simply a resource to mitigate crises or drive growth, but the vehicle through which the very foundations of life on Earth are redesigned. This narrative suggests that the key to navigating the Anthropocene is not to avoid catastrophic tipping points, but to anticipate and generate new forms of symbiosis between civilization and planet, where technology functions to restore lost balances, generate biodiversity and expand human capabilities without depleting resources. The challenge, then, is not just technological or social, but philosophical: It is about redefining what it means to thrive in a world co-created by humans and nature, and how to steer innovation towards a harmonious convergence between the two spheres.

If we were to start from an emerging narrative of "technological co-evolution" between natural and human systems, the future would be radically different from current projections, with a profound transformation in our relationship with the planet and our own technologies. Instead of seeing ourselves as mere stewards of natural resources, we would be co-creators in a system where nature and technology interact synergistically, with humanity playing a more balanced and responsible role in this interaction. In this future, technology would not be seen as a tool to exploit or mitigate, but as an extension of natural processes, designed to integrate and adapt to the biological and geological cycles of the planet. Cities, for example, would no longer be islands of asphalt and concrete separated from nature, but would become "urban ecosystems" where the infrastructure is literally alive: Buildings that regenerate air, harvest water and promote biodiversity, integrated into smart grids that interact with the surrounding ecosystems. Agricultural systems would be based on biomimetic processes inspired by natural ecosystems, managing resources, reducing waste and regenerating rather than degrading soils and in livestock systems, the inclusion of methane inhibitors in livestock feed and the use of microalgae and insects for manure treatment [65,66]. The reduction of methane emissions in livestock systems can be achieved through the implementation of several complementary technological strategies [65]. First, methane inhibitors, such as 3-nitrooxypropanol and cottonseeds, are incorporated into animal feed to block methanogenic bacterial enzymes in the rumen, achieving a 20%–40% reduction in emissions without compromising animal

productivity [67]. In parallel, manure treatment can be optimized through the use of microalgae [68], which consume nutrients in the manure as they grow, reducing methane emissions while producing biomass that can be used as fertilizer or animal feed, as well as purifying water and capturing CO_2 during photosynthesis. In addition, the use of insects such as the black soldier fly (Hermetia illucens L.) allows manure to be processed efficiently, accelerating the decomposition of organic matter and reducing the period of methane emission while transforming the waste into protein-rich biomass that can be used as food, achieving a reduction in odours and total waste volume [69].

The economies of the future would operate within a logic of regenerative abundance rather than extractive exploitation. Digital technology and artificial intelligence would be used not only to optimize resource use, but also to create new forms of wealth based on environmental restoration and ecological value creation. The concept of 'progress' would be redefined, not in terms of material expansion, but as the ability to coexist in dynamic equilibrium with the planet. Evolution would no longer focus exclusively on the ability to dominate the environment, but on how we adapt and evolve alongside it, creating a new global ethic based on cooperation between species, technological systems and ecosystems. The boundaries between the human, the natural and the artificial would be blurred, giving rise to new forms of hybrid life that combine the biological and the technological in symbiosis. This future is not without its challenges. Political and social decisions would be crucial to ensure that technological co-evolution does not perpetuate inequalities or create new ones. But with an ethical and critical vision, this path would lead us to a world in which humanity, instead of being a threat to the planet, becomes an agent of regeneration and coexistence, building a future in which flourishing means evolving alongside the natural environment, not at its expense.

4. Decarbonisation

Decarbonization is the comprehensive process of reducing man-made CO_2 emissions to a net zero state and is a cornerstone of the global strategy to combat climate change. This multi-faceted approach involves transformations in the energy, transport, industry and land-use sectors, driven by technological innovation, policy interventions and evolving market dynamics. It aims to limit global temperature rise in line with international climate agreements, which will require a profound transformation of economic models and energy systems. This transition presents both significant challenges and opportunities, promising to reshape economies, labor markets and societal norms as the world moves towards a sustainable, low-carbon future. Decarbonization is therefore not just a technical endeavour, but a fundamental redesign of human activities in balance with the Earth's climate system.

To understand the scale of the decarbonization challenge, it's important to examine the historical context of CO_2 emissions. The global concentration of carbon dioxide in the Earth's atmosphere has risen sharply since the start of the Industrial Revolution in the late 18th century, the period that marked the beginning of large-scale industrialization, when atmospheric CO_2 levels were around 280 parts per million (ppm). This was a natural balance that had remained relatively stable for thousands of

years. However, human activity, mainly through the burning of fossil fuels, deforestation and land-use change, has drastically disturbed this balance.

Currently, the concentration of CO_2 in the atmosphere will exceed 424 ppm by 2025 [70], an increase of more than 51% over pre-industrial levels (**Figure 1**).

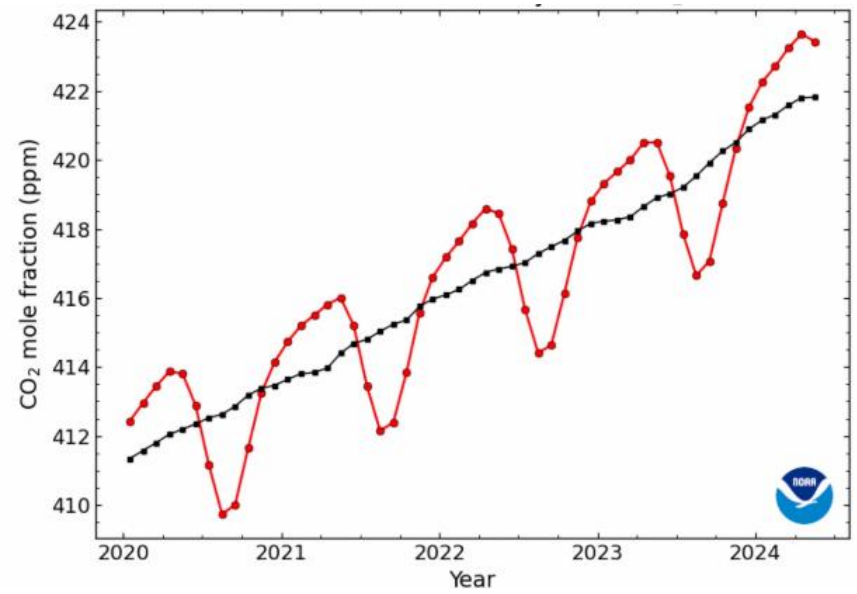

Figure 1. Global CO_2 concentration in ppm, 2025.
Source: [70]. Available in: https://gml.noaa.gov/ccgg/trends/global.html

The escalating concentration of CO_2 in the atmosphere poses a formidable challenge to global climate stability. With levels rising at an unprecedented rate of around 2.7 parts per million (ppm) per year (**Figure 2**), the scientific community has sounded the alarm about the potential consequences of unchecked carbon emissions. The IPCC has identified a critical threshold of 450 ppm atmospheric CO_2 concentration, which corresponds to a 2 °C increase in global temperature above pre-industrial levels [71]. Exceeding this threshold could trigger severe and irreversible climate change impacts, threatening ecosystems and human societies worldwide.

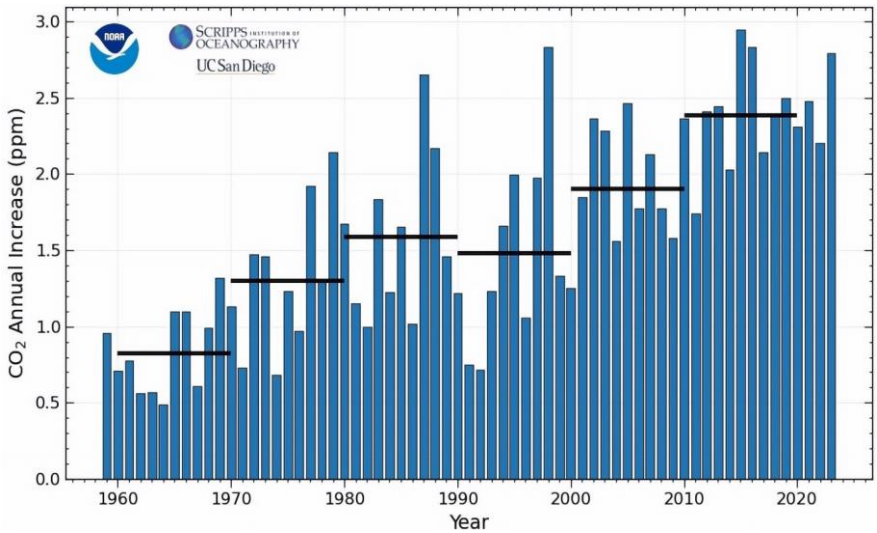

Figure 2. Annual global increase of CO_2, 2025.
Source: [70]. Available in: https://gml.noaa.gov/ccgg/trends/gl_gr.html

In response to this looming crisis, the international community has mobilized. The Paris Agreement on climate change, negotiated under the United Nations Framework Convention on Climate Change, represents a pivotal moment in global cooperation. Nations around the world have pledged to reduce greenhouse gas emissions, recognizing the urgent need for collective action to mitigate climate change. However, the persistence of rising CO_2 levels, coupled with the complexity of the transition to a low-carbon economy, suggests that emissions reduction alone may not be sufficient. This realization has brought the concept of decarbonization to the forefront of climate change strategies. Decarbonization aims not only to halt the upward trend in atmospheric CO_2, but also to stabilize concentrations at a level that avoids the most severe impacts of climate change.

Achieving this ambitious goal will require a two-pronged approach. First, CO_2 emissions must be drastically reduced across all sectors of the economy. This means transforming energy systems, industrial processes and consumption patterns to minimise carbon footprints. Second, and equally important, is the implementation of technologies and practices that can capture and sequester carbon already in the atmosphere [71].

Carbon dioxide removal (CDR) technologies and strategies have thus emerged as a critical component in the fight against climate change [72]. These range from nature-based solutions such as reforestation and soil carbon sequestration to more advanced technological interventions such as direct air capture and enhanced weathering. Integrating these CDR approaches into comprehensive climate action plans is becoming increasingly important as we seek not only to reduce future emissions, but also to deal with the legacy of past carbon pollution. The urgency of this dual approach cannot be overstated. As we continue to witness the effects of climate change - from extreme weather events to rising sea levels—the need for immediate and decisive action becomes ever more apparent. By combining aggressive emissions reductions with proactive carbon removal, we can hope to stabilise the Earth's climate system and protect the planet for future generations.

4.1. Background

Climate change has emerged as one of the world's most critical environmental challenges following two key milestones: the United Nations General Assembly's resolution 43/53 of 6 December 1988, which recognized climate change as a "common concern of mankind", and the subsequent adoption of the United Nations Framework Convention on Climate Change at the historic Earth Summit in Rio de Janeiro in 1992 [73]. In this context, global governance has developed mechanisms for cooperation to address climate change, including in particular the Montreal and Kyoto Protocols and the Paris Agreement.

4.1.1. Montreal protocol

The story of chlorofluorocarbons (CFCs) provides a compelling parallel to the earlier controversy over dichlorodiphenyltrichloroethane (DDT), highlighting the complex relationship between scientific innovation and environmental consequences. Both chemicals initially represented groundbreaking advances, offering promising solutions to everyday problems and industrial challenges. CFCs were long hailed as

almost miraculous compounds. These seemingly inert and harmless molecules found widespread application in various industrial and domestic sectors. Their versatility and apparent safety led to their integration into numerous products and processes, from refrigerants and aerosol propellants to cleaning solvents and foam-blowing agents. However, much like DDT two decades earlier, the initial enthusiasm for CFCs was tempered by growing scientific evidence of their harmful environmental effects. In the 1970s and 1980s, researchers began to uncover the role of CFCs in depleting the stratospheric ozone layer, which shields the Earth from harmful ultraviolet radiation. This discovery led to a paradigm shift in the way these chemicals were perceived and regulated.

The international response to the ozone depletion crisis culminated in the Montreal Protocol on Substances that Deplete the Ozone Layer, signed in 1987. This agreement was a watershed in environmental governance, demonstrating the ability of the global community to unite in the face of a common ecological threat. The Protocol's success in phasing out ozone-depleting substances has been widely hailed as one of the most effective international environmental treaties to date. Similarly, growing awareness of anthropogenic climate change towards the end of the 20th century led to the adoption of the Kyoto Protocol in 1997. This agreement, under the United Nations Framework Convention on Climate Change, aims to reduce greenhouse gas emissions and mitigate the effects of global warming. The parallel between CFCs and DDT, and the subsequent global responses to ozone depletion and climate change, illustrate several important lessons: i) the potential for unintended consequences of technological innovation, particularly when deployed on a global scale; ii) the critical role of scientific research in identifying environmental threats and informing policy decisions; iii) the importance of international cooperation and governance in addressing transboundary environmental issues; and iv) the capacity of global society to mobilize and take decisive action when faced with clear scientific evidence of environmental harm.

These historical examples underscore the complex interplay between scientific discovery, technological progress, environmental impacts and global governance. They serve as a powerful reminder of the need for precautionary approaches in the development and deployment of new technologies, as well as the continuing need for robust international frameworks to address global environmental challenges.

As we continue to grapple with today's environmental challenges, including the ongoing threat of climate change and emerging concerns such as microplastic pollution, the lessons of the CFC and DDT sagas remain highly relevant. They underscore the importance of maintaining vigilance, fostering scientific inquiry and supporting international cooperation in our ongoing efforts to protect the global environment and ensure a sustainable future for all. The versatility of CFCs has transformed many aspects of modern life. At home, they revolutionized refrigeration and air conditioning, making household appliances not only more efficient but also safer and more reliable. In industry, CFCs enabled the production of foams for a wide range of applications, from comfortable cushions to innovative food packaging and highly effective insulation. In addition, their use in aerosols greatly increased the efficiency and practicality of these products [74]. However, the perception of CFCs as harmless substances was challenged by scientific advances. Groundbreaking research

revealed an unexpected and alarming facet of these molecules: their chemical reactivity under the intense ultraviolet radiation conditions of the stratosphere. This discovery revealed the destructive potential of CFCs for the ozone layer, which is essential for protecting life on Earth from harmful solar radiation.

The discovery of the Antarctic ozone hole through satellite observations in the 1980s marked a pivotal moment in environmental science and policy. These satellite measurements provided irrefutable visual evidence of the devastating effects of chlorofluorocarbons (CFCs) on the Earth's atmosphere [75,76], offering a global perspective on ozone depletion that had previously been unattainable. The powerful images of the ozone hole not only consolidated scientific consensus, but also raised public awareness and catalyzed international action. This visual data played a crucial role in the negotiations that led to the Montreal Protocol, demonstrating the power of advanced technology in environmental monitoring and its ability to influence global policy. The case illustrates how clear, objective evidence can overcome skepticism, drive public engagement and accelerate cooperative global responses to environmental threats. It also set a precedent for the use of satellite technology to address other global environmental issues, underscoring the critical role of comprehensive monitoring systems in identifying, understanding and mitigating complex Earth system processes. These images not only provided critical scientific evidence, but also acted as a catalyst for global public awareness and political action. The revelation of the harmful effects of CFCs is an example of how advancing scientific knowledge can challenge long-held assumptions and reveal the unintended consequences of seemingly beneficial technological innovations. The evolution of global environmental governance, particularly in addressing the threats posed by chlorofluorocarbons (CFCs) and rising CO_2 emissions, provides a compelling narrative of international cooperation, scientific advocacy, and the complexities of balancing development and environmental protection.

The case of CFCs illustrates the critical importance of continuous and rigorous assessment of technologies and substances introduced into our environment. It also highlights the need for coordinated international responses to global environmental threats. In the face of considerable opposition and scientific uncertainty [76], environmentalists emerged as the leading voice in the global campaign to ban CFCs. Their persistent efforts culminated in the signing of the Montreal Protocol in 1987 [29], a landmark achievement in international environmental governance.

The Montreal Protocol, ratified by every nation on earth, set a clear path for eliminating the production and consumption of ozone-depleting substances [77]. This agreement is widely regarded as a triumph of international cooperation and evidence-based policy-making, demonstrating the potential for global action in the face of a common threat. However, the implementation of the Montreal Protocol revealed unforeseen challenges [78]. The CFC issue was perceived primarily as a problem of rich countries, leading to difficult and protracted negotiations. Developing countries, which had contributed minimally to the accumulation of CFCs in the atmosphere, rightly sought to expand their use of these compounds, particularly for refrigeration [79]. To address this imbalance, the Protocol's authors introduced the innovative principle of "common but differentiated responsibilities", recognizing the unequal burden of responsibility between developed and developing countries [29].

This principle allowed for a nuanced approach: Developed countries would immediately reduce their use of CFCs by 50%, while developing countries were allowed a 15% increase. Although these measures were intended to benefit developing countries, instances of corruption under the Protocol led in some cases to uncontrolled CFC consumption [80], highlighting the challenges of implementing global environmental agreements.

Rising CO_2 emissions were a second major global concern, again requiring coordinated international action.

4.1.2. Kyoto protocol

The adoption of the Kyoto Protocol in the late 1990s, which entered into force in 2005, marked a turning point in international climate policy by establishing a historic precedent for the differentiation of responsibilities among nations. This international agreement, based on the principle of "common but differentiated responsibilities", explicitly recognized that developed economies, as the main emitters and historical contributors to the accumulation of greenhouse gases since the industrialization era, should assume greater responsibility for reducing emissions [81]. The Protocol's architecture not only established differentiated mitigation commitments, but also established an innovative framework for international cooperation by requiring developed countries to provide additional financial resources and facilitate technology transfer to developing countries, recognizing that global participation in the mitigation effort would require substantial support to redress the imbalance in capabilities among countries and to ensure an equitable transition to a low-carbon economy [82].

The Kyoto Protocol established a framework to drive the transition to a low-carbon economy through three fundamental mechanisms [83]: the Clean Development Mechanism (CDM), which allowed developed countries to invest in emission reduction projects in developing countries while generating emission reduction certificates; Joint Implementation (JI), which facilitated cooperation between developed countries to implement joint projects and share technologies; and Emissions Trading (ET), which established an international carbon market and created economic incentives for emissions reductions. This transformative framework affected national economies by requiring developed countries to set binding emission reduction targets and develop mitigation policies while providing developing countries with access to finance and technology transfer for sustainable projects [83]. Sectoral transformation was particularly evident in three key areas: the energy sector, with significant momentum for renewable energy and energy efficiency; the industrial sector, through the adoption of clean technologies and process optimization; and the financial sector, through the creation of new financial instruments and carbon markets.

However, these mechanisms and their application were flawed due to a confluence of critical factors that undermined their global effectiveness [84]. The CDM suffered from an uneven geographical distribution that favoured large emerging economies such as China and India while marginalising less developed countries, as well as problems of additionality and excessive bureaucracy that discouraged small and medium-sized projects. JI was hampered by problems in verifying emissions reductions, lack of transparency and limited participation, while ET faced structural challenges such as initial over-allocation of permits, extreme volatility in carbon prices

and lack of coordination between systems. These specific problems were compounded by broader systemic deficiencies, including the absence of the United States as one of the world's largest emitters, the exclusion of developing countries from binding commitments, inadequate science-based reduction targets, and the lack of effective compliance and sanction mechanisms. This set of limitations demonstrated the weaknesses of the Protocol's top-down approach, which did not adequately take into account specific national circumstances and capabilities, and ultimately led to a fundamental rethink, embodied in the 2015 Paris Agreement, which adopted a more flexible and bottom-up approach to addressing the global climate challenge.

4.1.3. Paris agreement

The Paris Agreement represents an unprecedented milestone in the global fight against climate change, establishing a robust and dynamic international framework for coordinated climate action [85]. This historic pact structures a system in which each nation makes specific commitments to reduce its greenhouse gas emissions through Nationally Determined Contributions (NDCs), instruments that reflect each country's unique capabilities and circumstances. The architecture of the agreement rests on several key pillars: a periodic review system that drives the progressive increase in climate ambition; rigorous transparency mechanisms for monitoring and reporting emissions; comprehensive adaptation strategies that prioritize the needs of developing countries; and a climate finance framework that facilitates the mobilization of resources. The inclusion of market mechanisms and the emphasis on international cooperation catalyze the transition to a decarbonized economy.

Conferences of Parties (COPs) have emerged as the primary forum for materializing and strengthening these climate commitments [86]. COP21 in Paris marked a turning point by setting concrete targets to limit global temperature rise. Each subsequent conference has contributed significantly to the framework for climate action [86]: COP24 developed the operational rulebook for the Paris Agreement, COP26 consolidated specific commitments to reduce coal use and deforestation, while COP27 launched an innovative fund to address climate-related loss and damage. The recent COP29, to be held in Baku, Azerbaijan, in 2024, represents significant progress in the practical implementation of previous commitments. The establishment of a new climate finance target to mobilize $300 billion per year by 2035 is an example of growing ambition to support developing countries. The conference deepened the dialogue on a just energy transition, recognising the urgent need to ensure that the transition to a green economy equitably benefits all sectors of society and upholds workers' rights.

Despite the innovative and ambitious nature of the Paris Agreement, the persistence of rising emissions in some developed countries reveals deep contradictions between international commitments and national realities [85]. While the Agreement established an unprecedented framework through NDCs, periodic reviews, transparency mechanisms and adaptation strategies, effective implementation has faced significant obstacles. The evolution of the COPs, from the historic COP21 in Paris to the recent COP29 in Baku, has shown remarkable progress in terms of commitments and climate finance. However, the gap between commitments and concrete actions persists due to several factors: Resistance from fossil fuel dependent

industries, lack of political will to implement structural changes, prioritization of short-term economic interests over long-term climate goals, and disparities in implementation capacity between developed and developing countries [85]. The voluntary nature of commitments under the Paris Agreement, while facilitating broader global participation, has also allowed some countries (such as the US, Russia, India and China) to continue to increase emissions without facing consequences, highlighting the limitations of a system that fundamentally relies on political will and international pressure to be effective [85].

The evolution of international environmental agreements, from the Montreal Protocol to the recent COP29, has revealed lessons of mistrust and fragmentation in global environmental governance [87]. Science has demonstrated its ability to drive global environmental policy even in the face of uncertainty and resistance, while the effectiveness of international cooperation in addressing transboundary environmental problems has often been indifferent [88]. The incorporation of the principle of "common but differentiated responsibilities" into these legal frameworks has emphasized the importance of integrating equity and development needs into global environmental governance, allowing for the inclusive and effective participation of all nations. The evolutionary nature of this governance is evident in how the experience and lessons learned from pioneering agreements such as the Montreal Protocol have enriched and shaped the development of subsequent treaties, from the Kyoto Protocol to the Paris Agreement. These agreements, while often politically ineffective, have established precedents for the design of robust implementation and compliance mechanisms [87].

5. Anthropocene in transition: The decarbonisation paradigm

Human activities, particularly the use of fossil fuels for energy, have profoundly altered the composition of the atmosphere, significantly increasing the concentration of greenhouse gases (GHGs). These gases have the unique ability to absorb infrared radiation and re-emit it back to the Earth's surface, a natural process known as the greenhouse effect, which is essential for sustaining life on our planet. However, the disproportionate increase in GHG concentrations due to human activity has accelerated the rise in global temperatures, a phenomenon known as anthropogenic global warming.

It's important to recognize that GHGs have been present in the Earth's atmosphere since the formation of the planet. However, the onset of the Anthropocene epoch has witnessed unprecedented changes in GHG concentrations. From an analytical point of view, GHGs can be divided into two main groups: (i) anthropogenic GHGs, which are directly produced or amplified by human activities such as the burning of fossil fuels, deforestation and various industrial processes; and (ii) natural GHGs, which are emitted by the planet's inherent systems, including oceans, volcanoes and the decomposition of organic matter. This classification allows us to address two related but distinct challenges. Anthropogenic GHGs continue to pose a significant threat to global climate stability, despite international governance efforts embodied in agreements such as the Montreal Protocol (focused on protecting the ozone layer) and the Kyoto Protocol (aimed at reducing GHG emissions).

Implementation and enforcement of these agreements have been uneven and, in many cases, insufficient to counter the accelerating pace of emissions. Controlling natural greenhouse gases presents even more complex challenges. Emissions of nitrous oxide (N2O) and methane (CH4) are increasing at an alarming rate due to several factors: i) the thawing of permafrost in Arctic regions, releasing large amounts of previously trapped methane; ii) the intensification of forest fires and biomass burning, both natural and man-made; iii) the expansion of livestock activities, particularly cattle farming, which is a major source of methane; and iv) industrial processes in developing countries, where environmental regulations are often less stringent or poorly enforced.

The interaction between anthropogenic and natural greenhouse gas emissions creates a feedback loop that exacerbates global warming. For example, as human activities raise atmospheric temperatures, permafrost thaws, releasing more methane and amplifying the warming effect. This complex interaction underlines the need for a comprehensive approach to climate change.

International efforts to reduce greenhouse gas emissions have had mixed results. While the Montreal Protocol has been largely successful in phasing out ozone-depleting substances, which are also potent greenhouse gases, the Kyoto Protocol and subsequent agreements have faced significant challenges in achieving widespread compliance and meaningful reductions in carbon dioxide emissions.

The disparity in industrial development and environmental regulations between developed and developing countries further complicates global efforts to reduce GHG emissions. As developing countries pursue economic growth, they often rely on carbon-intensive industries and less stringent environmental standards, offsetting reductions achieved in more developed economies. To effectively address the complex issue of GHG emissions and their impact on the global climate, a multi-faceted approach is required: i) Strengthening and broadening international agreements to include both developed and developing countries, with mechanisms for technology transfer and financial support, ii) Investing in research and development of clean energy technologies to reduce dependence on fossil fuels, iii) Implementing policies to protect and restore natural carbon sinks such as forests and wetlands, iv) developing and deploying carbon capture and storage technologies to reduce emissions from existing industrial processes; v) promoting sustainable agricultural practices to reduce methane emissions from livestock and nitrous oxide emissions from soil management; and vi) increasing public awareness and education on the impacts of climate change.

These factors create a positive feedback loop in which global warming accelerates the release of more natural greenhouse gases, which in turn increases warming. The complexity of this situation requires a multi-faceted approach that addresses both the reduction of anthropogenic emissions and the mitigation of the effects of climate change. This means not only deploying clean and efficient technologies, but also protecting and restoring ecosystems that act as natural carbon sinks, such as forests and oceans. It is also essential to strengthen international cooperation to ensure that developing countries can adopt sustainable industrial practices without compromising their economic growth. This could include the transfer of clean technologies, increased financial support for adaptation, and the implementation of public policies that incentivize the transition to a renewable, low-

carbon economy. Addressing the greenhouse gas challenge in the Anthropocene requires a deep understanding of the complex interactions between human and natural systems, and a sustained global commitment to implement effective and equitable solutions.

However, these problems are compounded when it comes to the main greenhouse gas: CO_2, which accounts for 70% of greenhouse gases. CO_2 is at the forefront of the greenhouse gases driving climate change, with both anthropogenic and natural sources and effects. On the anthropogenic side, CO_2 is primarily produced by the combustion of fossil fuels, including oil, natural gas and coal, which form the backbone of global energy systems. Conversely, natural CO_2 emissions result from complex Earth system processes, in particular permafrost thawing and ocean dynamics.

The challenge of mitigating CO_2 is multifaceted. Even if we succeed in controlling 45% of anthropogenic CO_2 emissions [89], the remaining 55%—a consequence of the social metabolism of global society—will continue to exert a significant influence on the Earth system. When natural CO_2 emissions are included, the potential future scenario becomes alarmingly catastrophic [25].

According to the National Oceanic and Atmospheric Administration [70], while land plants and the world's oceans collectively absorb approximately half of the 40 billion tonnes of CO_2 pollution generated annually by human activities, atmospheric CO_2 levels continue to rise at an alarming rate. Historical data reveals a consistent acceleration in atmospheric CO_2 concentration, starting from an average annual increase of 0.8 ppm in the 1960s, doubling to 1.6 ppm in the 1980s, briefly stabilizing at 1.5 ppm during the 1990s, then rising to 2.0 ppm in the 2000s, and ultimately reaching 2.7 ppm per year in the most recent decade [70,71].

This accelerating trend underlines the growing imbalance between CO_2 emissions and the Earth's capacity to absorb them and highlights the urgency of mitigation efforts. The challenge is compounded by the long-lived nature of CO_2 in the atmosphere. CO_2 can persist for hundreds if not thousands of years [90], meaning that today's emissions will continue to influence climate well into the future. This persistence underlines a critical point: Stabilizing climate change requires reducing net CO_2 emissions to zero. If we emit more CO_2 than nature can absorb in its sinks (mainly oceans and forests), atmospheric CO_2 concentrations will continue to rise, exacerbating global warming. This reality has several important implications: i) Urgency of action: The accelerating rate of CO_2 increase emphasizes the need for immediate and drastic emission reductions; ii) Holistic approach: Addressing anthropogenic emissions alone is not enough. We must also consider strategies to enhance natural carbon sinks and possibly develop technologies to actively remove CO_2 from the atmosphere; iii) Long-term perspective: Given the atmospheric longevity of CO_2, climate mitigation strategies must take a multi-generational perspective and consider impacts well beyond the immediate timescale; iv) Balance between emissions and sinks: Achieving net-zero emissions requires not only reducing emissions, but also increasing the capacity of natural and artificial carbon sinks; v) Global cooperation: The transboundary nature of CO_2 emissions and their impacts requires an unprecedented level of international cooperation and coordinated action; vi) Technological innovation: Developing and scaling up technologies for carbon-neutral energy production and carbon capture and storage will be critical to achieving

emission reduction targets; and vii) Ecosystem conservation: Protecting and restoring natural carbon sinks, such as forests and oceans, is essential to maintain the Earth's capacity to absorb carbon.

From a practical perspective, three cases are analyzed: The economies of Saudi Arabia, Chile and Italy, which are striving to implement circular and regenerative economy principles in their territories, each with its own approach and challenges. In the case of Saudi Arabia [91], its strategy is framed by the Saudi Green Initiative (SGI), which aims to reduce emissions by 2060. An analysis based on the Leontief input-output model examines the economic criteria needed to achieve low-emission targets and identifies potential sources of finance for green projects. The study, which is aligned with the country's Vision 2030, forecasts growth in the green bond market of 15% by 2030 and 30% by 2060, equivalent to around $14 billion and $39 billion respectively. Annual GDP growth of 2.6% by 2030 and 2% by 2060 is forecast, with the creation of more than 23 million new jobs. For its part, Chile [92] has implemented initiatives such as the Circular Economy Roadmap, although it faces several obstacles. The main challenges include cultural resistance, limited public awareness, insufficient professional training, growing consumerism and inadequate technological infrastructure outside metropolitan areas. However, the country has strengths such as a sound regulatory framework, commitment to international environmental agreements and a growing interest in sustainability among the young population. The mining, agriculture and tourism sectors offer opportunities for implementing the principles of a regenerative economy. Italy [93], on the other hand, has focused its strategy on circular economy innovation and multisectoral network contracts as a solution to the problem of common natural resources. Research shows that circular economy innovation can improve the efficiency of investments in natural resource regeneration, while network contracts create a legal framework that prevents coordination failures and increases the effectiveness of individual willingness to act cooperatively. This approach provides original solutions to the 'tragedy of the commons' by combining circular economy and governance systems that take into account the heterogeneity of stakeholders.

The uniqueness of these cases lies in their different approaches to socio-environmental transition, each deeply rooted in its specific context and territorial reality. Saudi Arabia emerges as a paradigmatic case of transformation as it moves from an oil economy to a more sustainable model. Its strategy rests on two fundamental axes: economic diversification and the implementation of sophisticated green financial instruments that seek to catalyse this transition without compromising economic development. The Chilean case illustrates the paradox characteristic of emerging economies whose productive base depends on natural resources. The country faces the inherent tension between its traditional extractivist matrix and its growing sustainability aspirations, creating systemic frictions that require innovative and adaptive solutions. From its position in Southern Europe, Italy brings an innovative perspective to the debate. Its approach is characterised by the privileging of collaborative governance and the development of sophisticated mechanisms for the management of common goods, materialised in multi-sectoral network contracts that facilitate the transition to a circular economy.

This confluence not only suggests a global recognition of the urgent need to transform production systems in the face of the challenges of the Anthropocene, but also demonstrates the diversity of possible paths towards this common goal. The differences in their approaches also underline the impossibility of applying a single, universal solution and highlight the crucial importance of adapting circular and regenerative economy strategies to local contexts and the specific institutional capacities of each territory. This mosaic of approaches suggests that the transition to regenerative economic models in the Anthropocene will require a sophisticated articulation between financial innovation, cultural transformation and new governance frameworks, adapted to the socio-economic and environmental realities of each region [28].

6. Conclusion and strategies for a decarbonised future

6.1. Conclusion

The results of the analysis show that the transition to a decarbonized global economy faces enormous challenges. However, the transition from grey to green through a regenerative economy is not just a climate change mitigation strategy, but a pathway to a prosperous, just and sustainable future. Accelerating this transition requires a coordinated effort between governments, businesses and citizens. By applying the principles of a regenerative economy, we have the opportunity not only to avoid the worst effects of climate change, but also to build a more liveable and equitable world for all forms of life. However, the increasing concentration of CO_2 in the atmosphere reflects the global capitalist model, which continues to drive massive resource consumption, as evidenced by the brief dip in emissions observed during the COVID-19 pandemic, which was quickly reversed with economic recovery. Mitigating the 20 billion tonnes of CO_2 we produce each year requires urgent and coordinated global action. The complex interplay between anthropogenic and natural sources of CO_2, coupled with the long-lived nature of the gas in the atmosphere, presents a formidable challenge to climate change mitigation. Addressing this issue requires a multifaceted approach that combines aggressive emission reductions, enhancement of natural carbon sinks, technological innovation and global cooperation.

6.2. Strategies for a decarbonised future

Two key, interlinked strategies are proposed to address this challenge. The first is to transform land and agricultural systems to increase their natural capacity to absorb carbon. This includes halting deforestation, promoting regenerative agriculture and developing sustainable livestock systems. The second strategy is to restructure the global social metabolism, which would involve reducing consumption, promoting a circular economy, accelerating the transition to renewable energy, and rethinking economic growth in terms of sustainability rather than the infinite accumulation of wealth. Such an approach would require a profound rethink of social and economic values and unprecedented global cooperation. Resistance from entrenched interests and global inequalities in responsibility and development are major obstacles, but the scale of the climate crisis demands radical change. To achieve this, it is essential that

governments implement bold and visionary policies that drive green innovation and foster international cooperation. This transition will not be easy or linear, but the benefits—a stable climate, healthy ecosystems, resilient communities and a sustainable economy—fully justify the effort required. In moving towards this future, we must embrace a holistic vision that integrates the environmental, economic and social, creating a world where human prosperity and planetary health are mutually reinforcing and ushering in a new era in human history.

The analysis leads to an ethical and ontological debate by articulating the narrative of the Anthropocene and regenerative economics as a philosophical and practical paradigm. Beyond the proposed decarbonization strategies, it introduces the need to redefine human progress in a context where planetary boundaries are inescapable. It proposes an innovative approach based on technological co-evolution, in which human technologies integrate with natural cycles to promote planetary symbiosis. It also shows how historical patterns of CO_2 emissions, and their acceleration reveal the urgency of adaptive, intergenerational solutions, emphasizing that the challenge is not merely technical but intergenerational. This approach transforms our relationship with the planet, moving from an extractive logic to a co-creative role in building a regenerative system.

Finally, it is recommended to strengthen policies for sustainable land use and regenerative agriculture, as well as to redesign economic models toward a circular and regenerative economy.

First, strengthening land use and regenerative agriculture policies requires the establishment of a comprehensive policy framework that prioritises the conservation of critical ecosystems and the transition to regenerative agricultural practices, based on three interrelated strategic pillars: The implementation of strict measures to halt deforestation through satellite monitoring systems, effective sanctions and the creation of community-managed protected areas; the development of a robust system of incentives for the adoption of sustainable technologies in agricultural production, including smart agriculture, efficient irrigation systems and integrated pest management; and transforming livestock production into low environmental impact systems through manure treatment, which can be optimised through the use of microalgae that consume nutrients from manure as they grow, reducing methane emissions while producing biomass that can be used as fertiliser or animal feed, as well as purifying water and capturing CO_2 during photosynthesis. In addition, the use of insects such as the black soldier fly would allow manure to be processed efficiently, accelerating the decomposition of organic matter and reducing the period of methane emissions. To encourage these practices, a comprehensive support framework must be put in place, including differentiated economic incentives, technical assistance programs, innovative financing mechanisms and participatory monitoring systems, to ensure that this transformation is inclusive, equitable and directly benefits rural communities, indigenous peoples and family farmers, thereby improving rural livelihoods, strengthening food security and building more resilient food systems that respond to current and future challenges in the global agricultural sector.

Second, the transition to a circular and regenerative economy requires a profound rethinking of current production and consumption systems, as well as the principles that underpin the concept of economic progress. This approach proposes the creation

of regulatory and economic frameworks that encourage practices aimed at reducing the consumption of resources, promoting the recycling of materials and prioritising the use of renewable energy.

To achieve this transformation, it is essential that governments play a central role in implementing specific policies and measures. These include introducing carbon taxes that reflect the true environmental cost of emissions, providing subsidies to encourage the development and deployment of clean technologies, and negotiating international agreements that ensure equity and promote effective global cooperation. This transition is not only a technical one, but also a cultural and conceptual one, as it requires a redefinition of economic progress beyond unlimited growth to prioritize human well-being, ecosystem resilience and long-term sustainability. By adopting a circular and regenerative model, societies can move towards a future where economic development is in harmony with planetary boundaries and the needs of the natural environment.

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Article

The impact of governance and economic factors on Biocracy in the committed countries in COP28

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Abstract: Biocracy refers to a system of governance and decision-making that prioritizes the well-being and health of living systems, including ecosystems, species, and human communities. Biocracy promotes holistic, participatory, and adaptive management, integrating science, traditional knowledge, and collective decision-making. The goal is to cultivate a mutually enriching relationship between humans and the natural world. As a result, all human actions have an impact on Biocracy. This study covers annual data from 2010 to 2022 for a group of member countries of the COP28 with the percentage of emissions reduction needed to meet the 1.5-degree Celsius target by 2030 among current top emitters and employs the tobit panel model with a limited dependent variable (LDV). The primary economic variables that substantially influence Biocracy are GDP growth, foreign investment, inflation rate, employment, trade-related variables (exports and imports), and governance. The results indicate that the governance index and imports variable have the most significant positive effect on Biocracy, and the elasticity of governance has the largest impact on Biocracy among all the variables studied. The study's objective is to identify strategies to enhance Biocracy without hindering economic growth, with an emphasis on the role of good governance.

Keywords: Biocracy; governance; tobit panel model; COP 28
JEL Classification: C21; F30; F43; G10

1. Introduction

When discussing the Earth's natural system on a global scale, it is crucial to recognize that a single decision made with a timescale of millions of years, involving interactions with various factors and distributing tasks, will directly impact this natural system. The consequences of such decisions, whether international or regional, will be profound and long-lasting. To address this issue and engage in meaningful dialogue, we must utilize modern definitions, such as Biocracy, climate change, and their implications, and consider the potential consequences of ignoring these matters.

The first question raised is what is Biocracy?

The term Biocracy refers to a form of governance that prioritizes the well-being of all living beings, distinguishing it from democracy, which primarily serves human interests. In a Biocratic system, representatives would make decisions on behalf of non-human life, using proxies such as biodiversity and ecosystem health to gauge the best interests of the natural world, similar to how representative democracy operates on behalf of human citizens.

If we consider "Biocracy" in the context of respecting the environment, it could potentially refer to a system of governance or decision-making that prioritizes and values ecological sustainability and the well-being of ecosystems [1]. It may involve policies and practices that promote conservation, biodiversity, renewable resources,

and a harmonious relationship with the natural world [2].

Also, if we define "Biocracy" as the mix of governance and the environment, it could refer to a system of governance that integrates environmental considerations and sustainability principles into decision-making processes [3]. In a Biocratic system, environmental concerns and the well-being of ecosystems would be given significant weight and consideration when making policy choices and implementing regulations [4]. Therefore, the role of governance in Biocracy is key and important.

A Biocratic approach to governance would involve adopting policies that prioritize environmental protection, conservation, and sustainable resource management. It would aim to strike a balance between economic development and environmental sustainability, ensuring that the long-term health of the environment is taken into account when making decisions that may impact it [5].

While "Biocracy" may not be a widely used term, the concept of integrating environmental considerations into governance is gaining importance globally as societies recognize the need for sustainable development and ecological stewardship. Governments and organizations around the world are increasingly incorporating environmental concerns into their decision-making processes to address pressing issues such as climate change, biodiversity loss, and pollution [6].

It's worth noting that there are various approaches to environmental governance, and specific strategies and practices may differ depending on the country, region, or organization involved. The ultimate goal is to achieve a balance between human activities and the preservation of the natural environment for the benefit of current and future generations [7].

Since the environment is the number one issue in the world in the 21st century, but some politicians and social activists in America and Europe, with the start of environmental activists' activities around the world in the late 20th century, intended to confront this movement. They had no inclination to accept this reality and surrender to it, and the main reason for this was their development-oriented and consumerist worldview that prioritized economic growth over nature [8]. These politicians have always tried to accuse environmental activists, especially young people, of extremism, to keep them in a position of weakness and defense, and to prevent them from shaping public discourse around their agenda. However, with the start of the 21st century, the frequency and intensity of warnings from environmental scientists and climate experts to developed countries increased, and this led to a surge in global environmental activism [9]. According to the firm belief of bioconservatives, democracy is powerless to choose the right path for humanity's future because the laws that democracy seeks to impose on people are often in conflict with the laws governing nature [10–14]. Biocracy is a governance concept that transcends traditional democracy, promoting a holistic system where all living beings—humans, plants, animals, and others—possess equal opportunities and inherent rights to flourish and sustain their existence. The escalating climate crisis has sparked a contentious debate between two opposing perspectives. Proponents of bioconservatism argue that anthropocentric systems, such as democracy, are primarily responsible for this predicament [15]. In contrast, democracy advocates contend that mitigating climate threats poses an insurmountable challenge.

With the advancement of societies and the competition among nations to increase

domestic production and improve economic factors such as trade and foreign direct investment, the climate change threat has become a historical confrontation between humanity and nature. As shown in **Figure 1**, the top five countries with the highest levels of CO_2 emissions are China, America, India, Japan, and Germany [16].

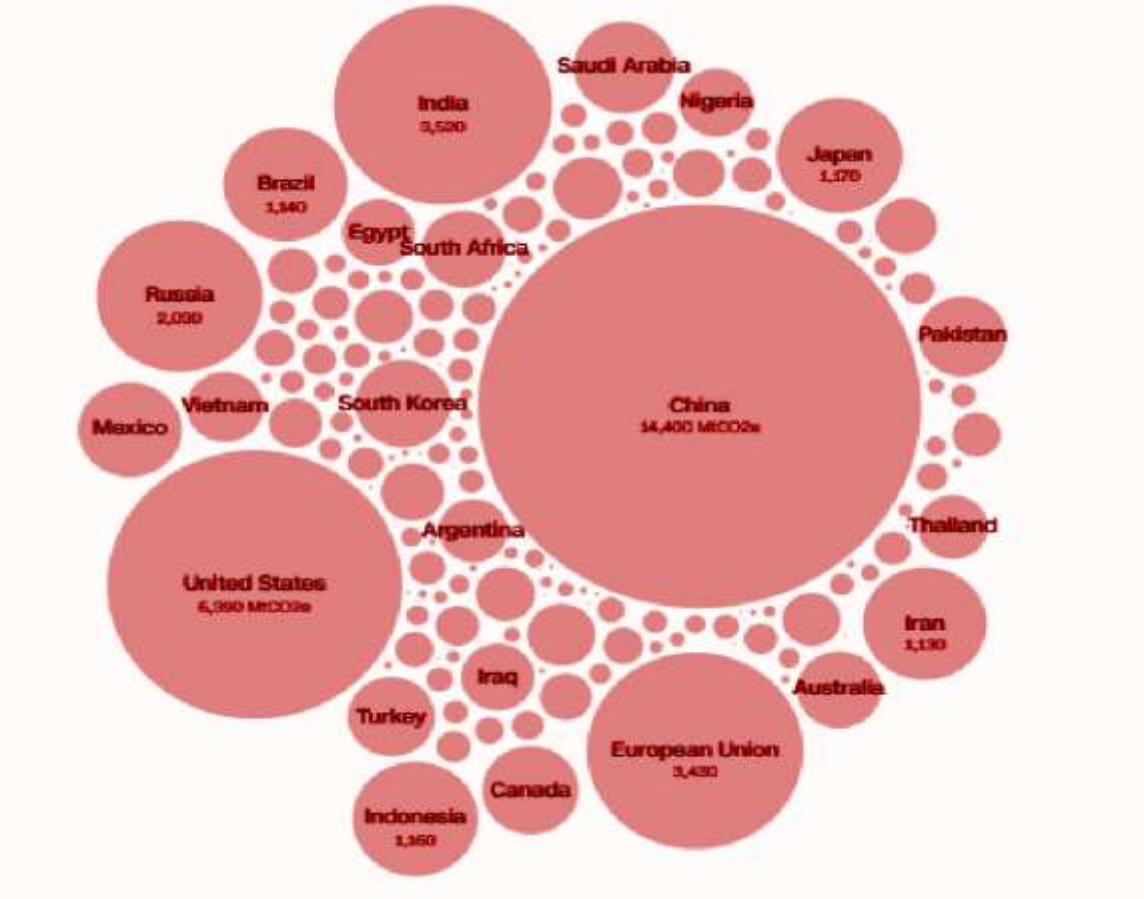

Figure 1. Total greenhouse gas emissions in 2022.
Sources: Climate Action Tracker, Gütschow and Pflüger [17].

According to **Figure 1**, the world pumped out around 50 billion metric tons of planet-heating gases in 2022. China was the largest climate polluter, making up nearly 30% of global emissions.

According to international organizations' announcements, if governments fail to reduce greenhouse gas emissions worldwide by 2050, the climate change trajectory will enter an irreversible phase, and this could lead to catastrophic consequences in the decades to come, such as mass extinctions and the destruction of life on Earth [18].

According to the Paris Agreement, member countries have committed to controlling climate change. If they don't fulfill their commitments and don't reduce greenhouse gas emissions by less than 10 billion tons per year by 2050, the Earth's temperature will rise above 4 degrees, which means that nearly 70% of the world's biodiversity will be lost from terrestrial and aquatic ecosystems, and this means the destruction of the world's ecosystems [19].

As shown in **Figure 2**, Global CO_2 emissions from fossil fuels and industry, in billion tonnes, 1965–2050. The chart shows historical emissions (black), the pre-Paris policy baseline (Grey, 2015 "current policies scenario"), the policy in 2021–2023

(blue, "stated policies scenarios"), as well as pledges in 2023 (red, "announced pledges scenario") and the IEA's suggested path to staying below 1.5C (yellow, "net-zero emissions by 2050 scenario"). If fulfilled, these pledges would result in emissions following the red line in the figure above. However, even meeting these climate commitments would still fall significantly short of what is required to limit warming to below 1.5 ℃ above pre-industrial temperatures, as indicated by the yellow line (Carbon Brief analysis by Simon Evans and Verner Viisainen of IEA world energy outlooks 2015–2023). But as shown in **Figures 3** and **4**, if countries do not commit to reducing greenhouse gas emissions, we will see deaths due to air pollution in many countries every year.

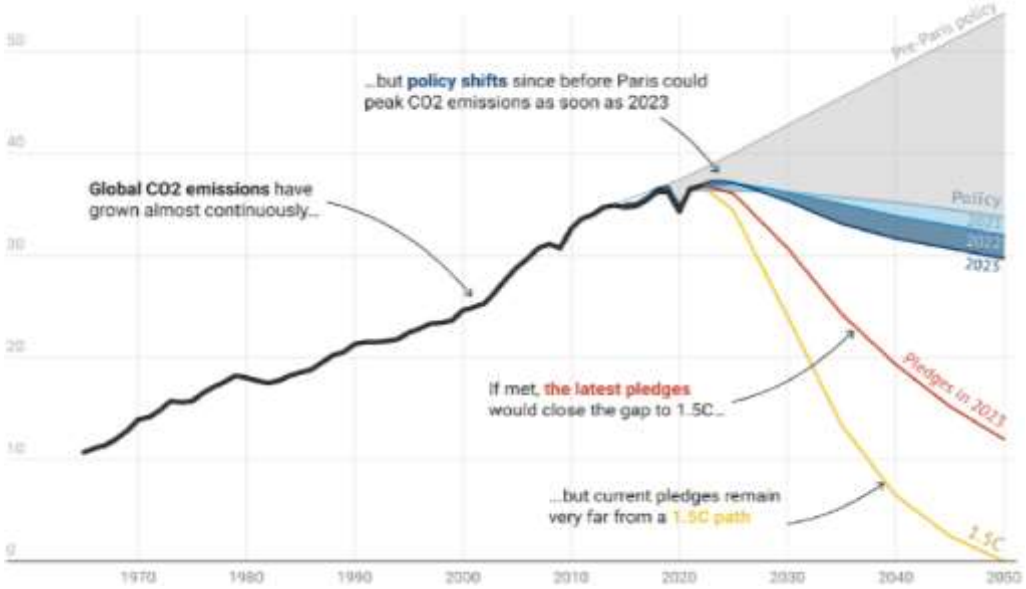

Figure 2. Global CO_2 emissions and policy scenarios.

Source: IEA[4] World energy outlooks [20].

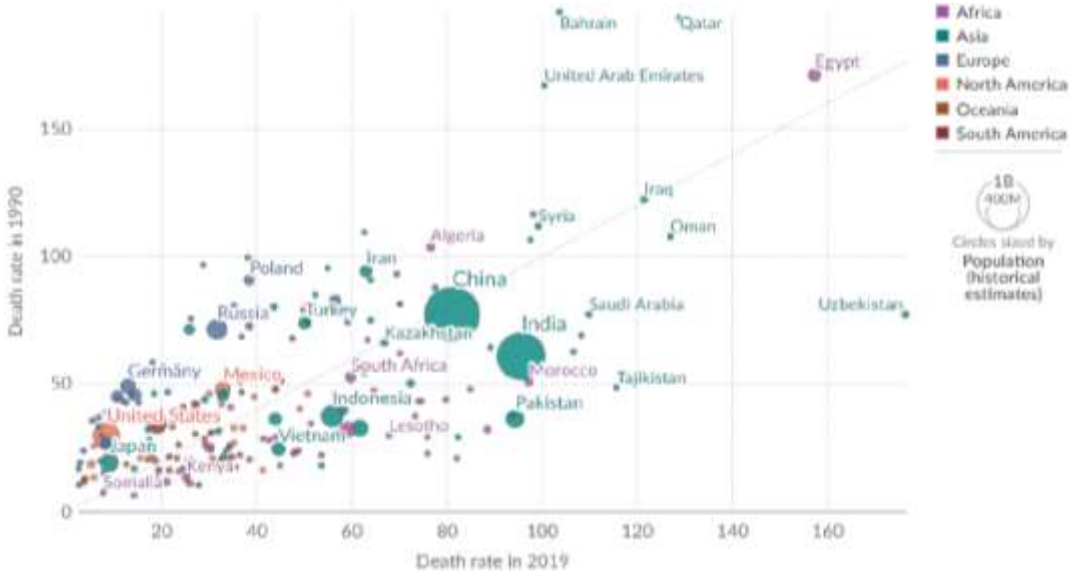

Figure 3. Death rate from outdoor air pollution in 1990 vs. 2019.

Data source: IHME, Global Burden of Disease [21]—Learn more about this data. Note: To allow comparisons between countries and over time, this metric is age-standardized. OurWorldInData.org/outdoor-air-pollution [21].

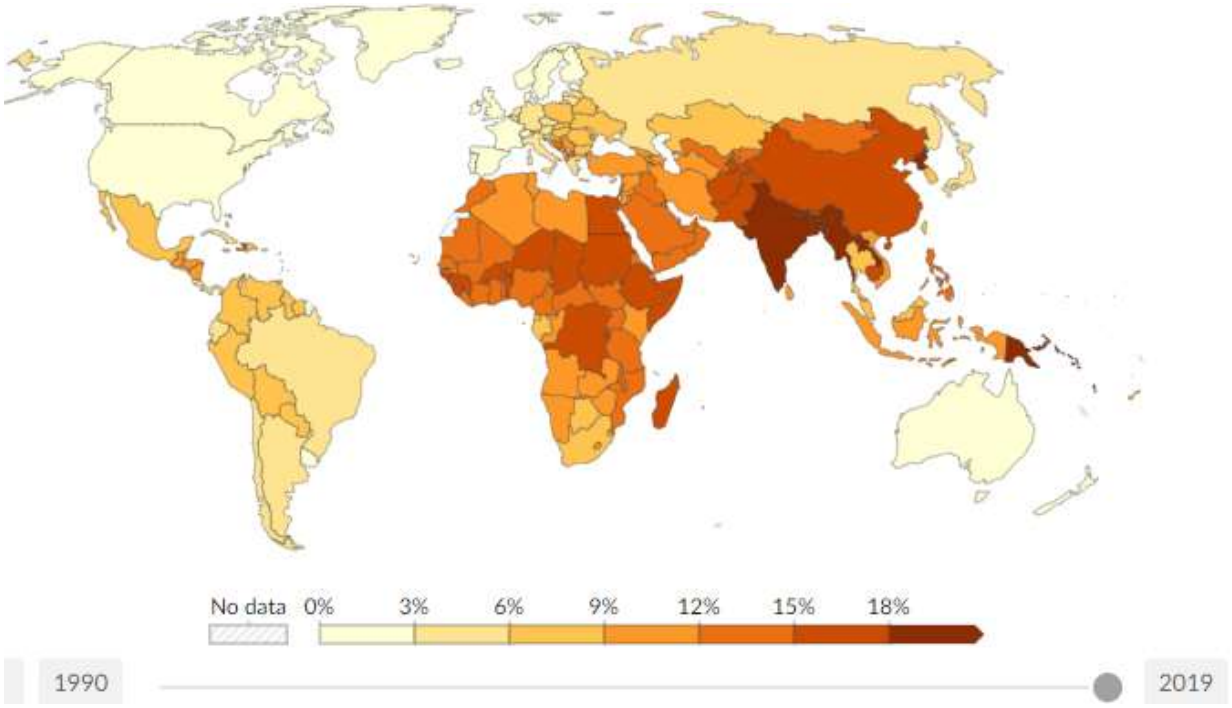

Figure 4. Share of deaths attributed to outdoor air pollution, 2019.

Note: Deaths from outdoor particulate matter air pollution per 100,000 people. Countries below the diagonal line have experienced an increased death rate, whilst those above the line have seen a decreased death rate. Data source: IHME, Global Burden of Disease [22]

Many studies focus on the impact of economic factors on environmental pollution [22–26]. One of the economic factors is foreign direct investment (FDI) and in recent decades its relationship with CO_2 emissions has been important for economic and environmental researchers. FDI indirectly affects the emission of environmental pollutants since it increases production in the country. Foreign investment has received much less attention from academic researchers compared with the relationship between economic growth and CO_2 emissions [27]. Studies such as those by Cheng and Liang [28], Feyzi [29], Kahuli and Chaaben [30], Yang and Zheng [31] show a positive relationship from FDI to pollutant emissions in the host countries. Amara et al. [32] also examine the relations between renewable CO_2 emissions, FDI, and economic growth in nine MENA countries from 2000 to 2019 using the geographic Durbin model based on spatial panel data. The empirical evidence supports the carbon emissions and FDI mediating the GDP-eco-innovation nexus Mahajan et al. [33] study the relationship between CO_2 emissions and GDP. Many climate-change studies support the positive links between GDP and trade with CO_2 emissions [34]. While several studies have examined the effects of economic factors and governance on CO_2 emissions [35–38], none of these studies have focused on the impact of governance along with economic factors on Biocracy, as well as the crucial role of governance in explaining environmental pollution in COP countries with the percentage of emissions reduction needed to meet the 1.5 degree Celsius target by 2030, among current top emitters (**Figure 5**). This research fills a gap by focusing on the impact of economic factors and governance on Biocracy.

This study investigates the following research questions:

1) What are the impacts of governance and economic factors on the Biocracy?

2) How does governance affect environmental pollution outcomes in the COP 28 member countries?

Based on the literature, the following null hypotheses are tested in this study:

H1: As GDP growth increases, Biocracy will decrease.

H2: As foreign investment increases, Biocracy will decrease.

H3: As imports increase, Biocracy will increase.

H4: As exports increase, Biocracy will decrease.

H5: As the Governance Index increases, Biocracy will increase.

H6: As the inflation rate increases, Biocracy will increase.

H7: As employment increases, Biocracy will decrease

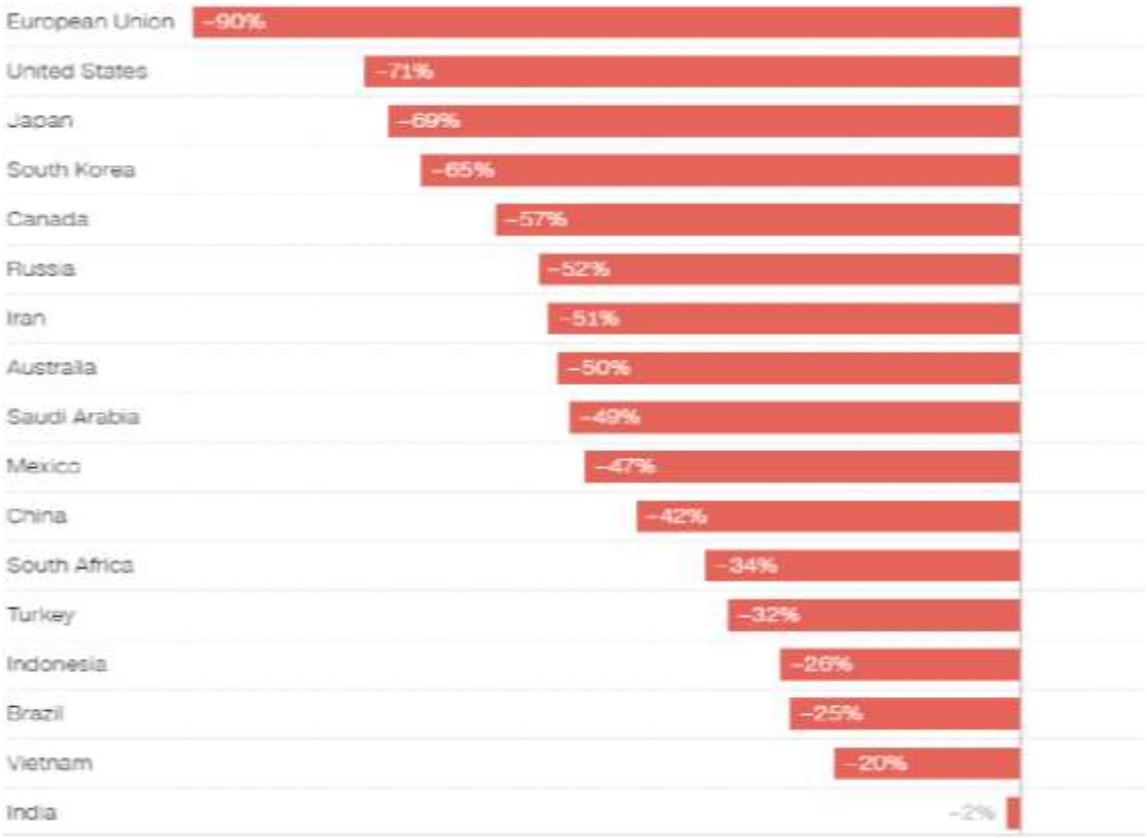

Figure 5. Percentage of emissions reduction needed to meet the 1.5-degree Celsius target by 2030, among current top emitters in COP28.

Note: This chart shows the percentage change from each country's 2022 emissions to its "fair share" emissions target, according to the Climate Action Tracker. Iraq and Pakistan are also among top 20 emitters but are not included in the Climate Action Tracker. Data updated on 20 November 2023. Sources: Climate Action Tracker, Gütschow and Pflüger [17].

2. Theoretical perspective

Biocracy refers to a system of governance or decision-making that prioritizes the well-being and health of living systems, such as ecosystems, species, and human communities. It emphasizes the importance of preserving biodiversity and the integrity of natural systems. In a Biocratic approach, decisions consider the long-term sustainability and resilience of the natural world. It seeks to redefine our relationship with nature, recognizing the intrinsic value of non-human life and ecosystem services. Biocracy encourages holistic, participatory, and adaptive management, integrating

science, traditional knowledge, and collective decision-making. The aim is to foster a mutually enriching relationship between humans and the rest of the natural world. Therefore, all human actions have an impact on Biocracy including trade.

According to a study published with Galvan et al. [39], there is a significant relationship between CO_2 emissions and trade. The study found that trade openness and FDI inflows lead to increased CO_2 emissions, while growth in GDP and services exports has a smaller but still positive impact on CO_2 emissions. Additionally, the study found that higher-income countries have a stronger positive impact of trade and FDI on CO_2 emissions compared to lower-middle-income countries.

Also, the relationship between CO_2 emissions and trade has been studied by various researchers. One notable study was conducted by Zhang et al. [40] who analyzed the nexus between CO_2 emissions, economic growth, trade openness, and FDI inflows in Latin American countries. Another study by Liu et al. [41] estimated the embodied CO_2 emissions in global trade and found significant variations across countries and products. Additionally, researchers have explored the environmental impact of trade agreements like NAFTA, suggesting that lowering trade barriers can lead to increased economic activity, changing production techniques, and subsequently affecting CO_2 emissions. The existing literature underscores the importance of examining the interplay between trade and carbon dioxide emissions, with previous findings offering a foundation for our investigation.

Foreign direct investment is another economic variable that is formed by humans and affects bureaucracy. According to the study "The Impacts of FDI Inflows on Carbon Emissions: Economic Development and Regulatory Quality as Moderators" by Huang et al. [42], FDI inflows have a positive effect on carbon emissions, while economic development and regulatory quality have a negative effect. Additionally, the study finds that FDI inflows tend to increase carbon emissions in countries with lower levels of economic development and weaker regulatory quality. The impact of FDI on environmental pollution is a vital issue that requires examination, and our research will contribute to the understanding of this critical relationship.

In addition, the inflation rate has always had a special place in the economy, so many studies have been conducted in this field. Researchers have studied the impact of carbon pricing on inflation rates. One study of Brand et al. [43] found that a €140 per ton CO_2 price would increase inflation by less than 0.2 percentage points annually. Another study suggested that the Inflation Reduction Act of 2022 could reduce emissions but may not fully offset the impact of inflation [44]. Additionally, a working paper of Moessner [45] examined how carbon pricing has affected inflation ex post across 35 OECD economies from 1995 to 2020.

Researchers have studied the impact of carbon pricing on employment, finding both positive and negative effects depending on the context and policy design [46]. In a study in the same field, Heutel [47] studied the impact of CO_2 emissions on employment in the US and found that a 10% reduction in emissions would lead to a 0.22% increase in employment. Another study proposed a carbon tax and subsidy reform that could create jobs while reducing emissions [48]. However, it's important to consider the specific context and policy design when evaluating the impact on employment.

The literature review highlights GDP growth, foreign investment, inflation rate,

employment, and trade-related variables (exports and imports) as the most critical economic factors, given the significant impact of trade on environmental pollution. Given the crucial impact of governance on environmental pollution control, the Rule of Law index is used as an explanatory variable to reduce environmental pollution and control climate change [49]. Additionally, due to the special importance of greenhouse gas emissions, including carbon dioxide, in air pollution and climate change, the percentage reduction of this variable is considered a Biocracy index in COP28 countries in this study [50].

While the interconnections between economic factors, governance, and CO_2 emissions have been investigated, the specific influence of governance and economic factors on Biocracy, as well as governance's role in addressing environmental pollution in COP countries, requires further examination. This study bridges this research gap, focusing on the critical need for emissions reduction in top-emitting countries to meet the 1.5 ℃ target by 2030.

3. Methodology

In this article, the Panel Tobit model is used following Bruno [51]; Busse et al. [52]; Khan et al. [53], and Chang [54]. In a Panel Tobit model, individual-specific and time-invariant effects are accounted for as random effects, whereas a fixed effects model is susceptible to the incidental parameter problem. However, in data-censoring applications, assuming H0: $\bar{\xi} = 0$, adding $\bar{X}i$ to the random effects Tobit model addresses the issue of unobserved heterogeneity, as suggested by Wooldridge [55].

$$Yit = \beta Xit + Ci + uit \quad t = 1,2,\ldots..,T \tag{1}$$

$$Ci = \psi + Xi\xi + \alpha i \tag{2}$$

where *Ci* represents the unobserved effect and *Xi* encompasses *Xit* for all time periods *t*. This model represents a data-censoring framework, which is the primary focus of interest.

This study employs panel data with a limited dependent variable (LDV) in its analysis. Like the Tobit method, in this model, a threshold level is defined so that the data above it is visible and the data below it is considered censored or zero.

According to the literature review, the primary economic variables that substantially influence Biocracy are GDP growth, foreign investment, inflation rate, employment, and trade-related variables (exports and imports). These factors are critical since trade significantly contributes to environmental pollution. Additionally, the Rule of Law index is employed as an explanatory variable to mitigate environmental pollution and address climate change, highlighting the essential role of governance in environmental pollution control [56].

PANEL TOBIT MODEL:

A key challenge in panel data models is estimating Limited Dependent Variable (LDV) models, which involve lagged dependent variables and serially correlated errors. Traditional methods for linear panel data models are not applicable to panel Tobit models due to their unique structure, use of lagged variables, and time-dummy variables. However, the random effects approach can be employed by specifying the error distribution conditional on regressors and maximizing the likelihood function.

This approach accommodates time-invariant, time-varying, and time-dummy variables, and offers straightforward identification under normally distributed errors [57]. The Panel Tobit model's econometric structure follows the format presented by Brown [58]:

$$y \times it = \beta' xit + uit \qquad i = 1,2, \ldots\ldots, N \quad t = 1,2, \ldots\ldots, T \tag{3}$$

$$uit = vi + \varepsilon it \qquad (vi \sim NID(0, \sigma 2v)) \quad (\varepsilon it \sim NID(0, \sigma 2\varepsilon)) \tag{4}$$

where the observed variables are:

$$yit = \{y * it \quad if \;\; y * it > 00 \quad and\; 0 \;\; otherwise \tag{5}$$

where *y* is a binary dependent variable and the x's are independent variables. The common error term, *uit* in Equation (4), exhibits temporal autocorrelation. The error component model decomposes *uit* into a time-invariant individual random effect (RE), *vi*, and a time-varying idiosyncratic random error, it. Assuming independence between *v*'s and Ɛ's, and defining *dit* = 1 for uncensored observations and *dit* = 0 for censored observations, the likelihood function for each individual, marginalized with respect to the random effect *vi*, is:

$$lit = \int \infty - \infty [1/\sigma\varepsilon \,.\, \emptyset((yit - \;\beta' xit + vi)/\sigma\varepsilon)] dit. [\Phi(-\beta' xit + vi)/\sigma\varepsilon)](1 - dit) f(vi, \sigma i) dvi \tag{6}$$

where: $\phi(.)$ represents the probability density function and $\Phi(.)$ represents the cumulative distribution function of the standard normal distribution, f (*v*i, σi) denotes a normal density with mean vi and standard deviation σi. For T_i observations, the likelihood function is:

$$Lit = \int \infty - \infty \prod t = 1t = Ti. [1\sigma\varepsilon\emptyset(yit - \;\beta' xit + vi\sigma\varepsilon)] dit. [\Phi(-\beta' xit + vi\sigma\varepsilon)](1 - dit) f(vi, \sigma i) dvi \tag{7}$$

In this study, Biocracy is the dependent variable, and the independent variables are GDP growth, foreign investment, inflation rate, employment, trade-related variables (exports and imports) and governance. All independent variables are chosen based on the Wald test and the Lm test with a significance level of 5%. Thus, all the included independent variables add significant explanatory power to the model and removing anyone reduces the model's fit. The hypothesis of random effects is not rejected by the Breusch-Pagan test, so the empirical model is as follows:

$$Biocracy = \vdash BSit \quad if \;\; yit > 0 \quad other\, wise \;\; 0 \tag{8}$$

$$y \cdot it = \beta GDPit + \beta FIit + \beta INit + \beta IMit + \beta EXPit + \beta EMPit + \beta GOVit + uit \;\; i = 1,2, \ldots\ldots, N$$
$$Uit = vi + \varepsilon it \qquad (vi \sim NID(0, \sigma 2v)) \quad (\varepsilon it \sim NID(0, \sigma 2\varepsilon)) \tag{9}$$

$$Lit = \int \infty - \infty [1\sigma\epsilon\phi(yit \; - \; \beta GDPit - \beta FIit - \beta IMit - \beta EXPit - \beta INit - \beta EMPit - \beta GOVit + vit\sigma\epsilon)] dit.$$
$$. \; \Phi(-\beta GDPit - \beta INit - \beta EXit - \beta IMit - \beta FIit - -\beta EMPit - \beta GOVit + vit\sigma\epsilon\sigma i)(1 - dit) f(vi, \sigma i). \; \Phi \tag{10}$$

The sample likelihood function is the product of the L_i over the N individuals

$$L = \sum ln(li) \tag{11}$$

Equation (11) does not collapse into a sum because it is an integral of a product. Intercedence among the observations prevents parceling out the likelihood contribution of the *Ti* periods for the *i* individual when serial correlation is present.

Classical estimation methods are infeasible in a T-dimensional integral when the number of time periods is more than three or four.

In this paper, the feasible maximum likelihood estimation for limited dependent variable panel data is available for a particularly simple structure of the random disturbance and we use STATA for the panel Tobit models. The random effects model estimation assumes that εit is serially uncorrelated, the vi are uncorrelated across individuals, and $vi \mid xi \sim\sim NID\ (0, \sigma 2)$.

4. Data description and analyses

This study covers annual data from 2010 to 2022 for a group of member countries of the COP with the percentage of emissions reduction needed to meet the 1.5-degree Celsius target by 2030, among current top emitters (**Figure 5.**). Panel data refers to a dataset comprising a large number of cross-sectional observations (N) collected over a prolonged period (T). Panel data is a type of data that is collected over time for multiple individuals, firms, or other units of analysis. Some important properties of panel data include:

- Time dimension: Panel data has a time dimension, which allows for analysis of changes, trends, and patterns over time.
- Cross-sectional dimension: Panel data also has a cross-sectional dimension, which allows for analysis of differences between individuals, firms, or other units of analysis at a given point in time.
- Longitudinal nature: Panel data is collected over time for the same units of analysis, allowing for the study of longitudinal relationships and development.
- Repeated measurements: Panel data involves repeated measurements of the same variables over time, enabling analysis of changes and trends.

The descriptive statistics of the variables are shown in **Table 1**.

Table 1. Descriptive statistics of the variables in the model.

Variable	Maximum	Minimum	Standard Deviation	Mean
Biocracy	1.09e + 07	457.4	2610849	9812.17
Gross Domestic Production	11.43	−8.56	3.15	3.26
Employment	57.4	1.32	16.43	16.70
Foreign Direct Investment	9.37e + 11	−1.31e + 11	1.69e + 11	8.43e + 11
Inflation rate	72.30	−2.09	5981.39	3397.95
Export	1.13e + 13	7.78e + 09	2.15e + 12	1.25e + 12
Import	1.09e + 12	1.29e + 10	2.04e + 12	1.23e + 12
Governance	1.91	−1.72	0.98	0.25

Source: Research findings.

"In math, "e" stands for "exponent" and is used in scientific notation to represent a power of 10; so, "1.09e + 07" means 1.09 multiplied by 10 to the power of 7, which is equal to 10,900,000."

Initially, stationarity is assessed using Fisher's generalized unit root test [59]. The results of the Fisher test for panel data indicate that the null hypothesis of a unit root is rejected at the 5% level of significance (**Table 2**), suggesting stationarity.

Additionally, the cross-sectional correlation test using the Freeze test (**Table 2**) rejects the null hypothesis of no correlation at the 5% level of significance. To determine the appropriate model specification, a Hausman test is conducted to compare fixed and random effects models. The null hypothesis of no fixed effects is accepted (**Table 3**), leading to the selection of a random effects model.

Table 2. The Fisher unit root test results and freeze test.

Method	**Value**	***P* value**
Chi-Square and Fisher Dickey Fuller	162.21	0.01
Freeze Cross-Section Correlation	158.02	0.02

Source: Research findings.

Table 3. Hausman test results.

Test Hausman	***P* value**
Hausman Fe, Re	1.00

Source: Research findings. Notes: Breusch Pagan test probability distribution $p = 0/00$.

5. Results

In this investigation, the impacts of Economic and Governance factors on Biocracy are evaluated using the tobit panel model, and the resulting estimates are presented in **Table 4**. Governance has a positive relationship with Biocracy. An increase in governance means an increase in Biocracy. For example, as the Governance (Rule of Law) index increases, the enforcement of laws across all areas of a country intensifies. Consequently, factories causing air pollution will be compelled to halt operations unless they take corrective measures to address this issue. In the tobit panel method, the coefficients must be transformed in order to determine the elasticities (**Table 5**). The total elasticity is the effect of one percentage change in x on y. The elasticity of the Governance is 0.42. Specifically, a one percent increase in the variable is associated with a 0.42% increase in Biocracy, indicating a positive correlation between the two variables. This elasticity has the largest impact on Biocracy among all the variables studied [60,61]. Governance has a significant impact on biodiversity. Effective governance can promote conservation and sustainable use of biodiversity, while poor governance can lead to habitat destruction, overexploitation of resources, and loss of species. Some ways governance affects biodiversity include the rule of law that means governments can establish laws and policies to protect habitats, regulate resource use, and promote sustainable practices. The outcome supports the research hypothesis, indicating that enhancements in governance, as measured by the governance index, are linked to increased Biocracy development, thereby addressing the first research question.

Increasing exports decreases Biocracy (**Table 4**). Li et al. [62] also discovered a negative relationship between exports and Biocracy (reducing carbon dioxide emissions). The elasticity of exports is 0.32. This indicates that a 1% increase in exports leads to a 0.32% decrease in Biocracy, assuming all other factors remain constant. This outcome stems from the fact that boosting exports necessitates augmenting production, packaging, and marketing processes. These stages entail

increased fuel energy consumption for factory machines, transportation, and other devices, resulting in elevated environmental pollution and emissions. Notably, the byproduct of this process includes carbon dioxide, a harmful greenhouse gas [63]. The findings align with the first research question and support the research hypothesis, which posits that a higher export is associated with decreased Biocracy. Other negative effects of trade on the environment include:

- Habitat destruction: Trade in natural resources can lead to habitat destruction and degradation.
- Overexploitation: High demand for resources through trade can result in overexploitation and depletion of species populations.
- Invasive species: Trade can facilitate the intentional or accidental introduction of invasive species, which can harm native ecosystems.
- Illegal wildlife trade: Illegal trade in wildlife and wildlife products, such as rhino horn and elephant tusks, can drive population declines and even extinctions.

To mitigate the negative impacts, sustainable trade practices, certification schemes, and regulations are essential to ensure that trade supports biodiversity conservation and responsible resource use [64].

The findings suggest that an increase in imports for a COP member country has a positive impact on Biocracy. This outcome is counterintuitive, as one might expect imports to reduce domestic production, leading to decreased CO_2 emissions and increased Biocracy. However, the results indicate that imports complement rather than replace domestic production, resulting in enhanced Biocracy in COP countries. The elasticity of imports is 0.38. Specifically, a one percent increase in the variable is associated with a 0.38% increase in Biocracy.

Expanding employment opportunities diminishes Biocracy, consistent with Kopidou et al.'s [65] findings. As employment rises, domestic production increases, leading to greater machine and equipment usage, resulting in elevated carbon dioxide emissions and air pollution. Notably, the employment elasticity is −0.31, indicating that a 1% increase in employment corresponds to a 0.31% decrease in Biocracy. The outcome supports the research hypothesis.

The GDP variable also has a negative relationship with Biocracy which is similar to the finding of Kumar et al. [66]. An increase in production causes an increase in the use of fuel and energy, an increase in air pollution and a decrease in Biocracy. Notably, the GDP elasticity is −0.37, indicating that a 1% increase in employment corresponds to a 0.37% decrease in Biocracy.

Increasing Foreign Direct Investment (FDI) reduces Biocracy, consistent with Hoa et al.'s [67] finding. Rising FDI significantly impacts production, leading to increased fuel and energy consumption, air pollution, and a decrease in Biocracy. The elasticity of the consumer price is −0.26, indicating that a 1% increase in FDI corresponds to a 0.26% decrease in Biocracy.

The results indicate that an increase in the inflation rate for a COP member country has a positive effect on Biocracy, although the coefficient fails to reach statistical significance at the 5% level. This result confirms the first research question and is consistent with the study's hypothesis, suggesting a positive correlation between the inflation rate for a COP member country and Biocracy.

Table 4. The results of the tobit panel.

Variables	Coefficient Estimates	*Z* statistics	Standard Deviation Estimates	*P* value
Governance	270639.8	11.19	28185.21	0.00
Gross Domestic Production	−14920.48	−2.57	5799.77	0.01
Employment	−41575.32	−9.98	4165.46	0.00
Foreign Direct Investment	−5.39e−07	−3.15	1.71e-07	0.002
Inflation rate	841.89	0.29	2884.69	0.22
Export	−3.58e-07	−3.19	1.12e-07	0.04
Import	3.37e-07	3.24	1.04e-07	0.24
Sigma u	0.00			
Sigma e	200371.8			0.00
Rho	0.00			

Source: Research findings.

Table 5. Elasticity frequency of independent variables.

Variable	Total Elasticity	*Z* statistics	Standard Deviation Estimates
Foreign Direct Investment	−0.26 ***	−10.98	0.024
Gross Domestic Production	−0.37***	−2.80	0.13
Employment	−0.31***	−9.12	0.034
Governance	0.42***	3.81	0.11
Inflation rate	0.20	0.78	0.25
Export	−0.32***	−3.15	0.10
Import	0.38**	3.34	0.11

Notes: *, **, *** denote statistical significance at the 10%, 5%, and 1% levels, respectively. Source: Research findings.

6. Conclusions

The contemporary world faces numerous environmental challenges, with the emission of pollutants and greenhouse gases posing a significant threat to human life on the planet. However, studies on environmental mitigation and CO_2 emissions have largely overlooked the critical role of COP countries in reducing carbon dioxide emissions by 2023. This research aims to investigate the impact of six economic factors (GDP growth, foreign investment, inflation rate, employment, and trade-related variables (exports and imports)) and a governance indicator on Biocracy from 2010 to 2022 for a group of member countries of the COP with the percentage of emissions reduction needed to meet the 1.5-degree Celsius target by 2030, among current top emitters. The results indicate that the governance index and imports variable have the most significant positive effect on Biocracy. The study's objective is to identify strategies to enhance Biocracy without hindering economic growth, with an emphasis on the role of good governance. The findings are particularly challenging for COP member countries with high levels of air pollution, as various factors like GDP, exports, FDI, and employment are currently contributing to decreased Biocracy. Only governance and imports have the potential to reduce emissions while promoting economic well-being, with imports shifting emissions from the importer to the exporter. Therefore, governance emerges as the crucial factor in increasing Biocracy,

and COP countries have significant scope for improvement.

However, achieving this requires major political changes that empower civil society, NGOs, and responsive government.

This research makes suggestions to enhance governance and mitigate pollution, as follows:

Effective Policy Implementation:

1) Clear regulations: Establishing and enforcing strict environmental regulations and standards.
2) Monitoring and enforcement: Regular monitoring and enforcement of environmental laws and policies.

Transparency and Accountability:

1) Public access to information: Providing citizens with access to environmental data and information.
2) Participatory decision-making: Involving citizens, NGOs, and other stakeholders in environmental decision-making processes.
3) Accountability mechanisms: Establishing mechanisms to hold officials and polluters accountable for environmental damage.

Efficient Resource Management:

1) Sustainable resource use: Promoting sustainable use of natural resources, such as water and land.
2) Waste management: Implementing effective waste management systems to reduce pollution.

Public Education and Awareness:

1) Environmental education: Promoting environmental education and awareness among citizens.
2) Public awareness campaigns: Launching public awareness campaigns to promote environmentally friendly behaviors.

Collaboration and Partnerships:

1) Interagency coordination: Fostering coordination and cooperation among government agencies, NGOs, and private sector entities.
2) International cooperation: Collaborating with international organizations and governments to address transboundary environmental issues.

Incentives for Sustainable Practices:

1) Economic incentives: Offering economic incentives, such as tax breaks or subsidies, for sustainable practices.
2) Recognition and rewards: Recognizing and rewarding individuals and organizations that adopt environmentally friendly practices.

By implementing these measures, good governance can play a crucial role in reducing environmental pollution and promoting Biocracy.

However, good governance benefits extend beyond national borders, promoting clean technology diffusion and climate-friendly energy access in developing countries [68]. Removing trade barriers can boost clean technology trade, but developing countries face obstacles like low environmental standards and weak regulations [69]. Selected COP countries are becoming major clean technology manufacturers, and policy improvements can enhance environmental sustainability (Environmental Permitting, 2023). Effective governance is crucial to overcoming pushback against

environmental policies and promoting cleaner technologies, ensuring a sustainable future.

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Abbreviations

LDV	limited dependent variable
CO_2	Carbon dioxide
COP28	Conference of the Parties
FDI	Foreign direct investment
GDP	Gross Domestic Product
IEA	International energy agency
IHME	Institute for Health Metrics and Evaluation
IMF	International Monetary Fund
UN	UNITED NATION
UNFCCC	United Nations' Framework Convention on Climate Change
WJP	world justice project

Notes

[1] International Monetary Fund
[2] UNITED NATION
[3] UN Climate Change Conferences
[4] International Energy Agency

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Article

Financial literacy, financial inclusion, and food security: A comparative analysis of green and blue economy in the poorest region of Luzon, Philippines

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Abstract: The study aims to analyze the differences and influences of financial literacy and financial inclusion on food security in the green and blue economies of San Jose, Camarines Sur, located within the poorest region of Luzon, Philippines. The research also seeks to determine the levels of financial literacy, inclusion, and food security among specific members of each economy, namely rice farmers in the green economy and fisherfolk in the blue economy. This study employs a causal-comparative research design utilizing weighted mean, Kruskal-Walli's test, and multivariate linear regression to assess the levels, variances, and impacts of financial literacy, inclusion, and food security. The findings indicate that both the green and blue economies exhibit low levels of financial literacy, as individuals struggle to apply their knowledge and skills to their attitudes and behaviors. Furthermore, given that many rice farmers and a majority of fisherfolk reside in remote areas away from urban centers, they encounter challenges in accessing and effectively utilizing financial services and products. Additionally, due to their informal income status, they experience transient food insecurity. The study highlights a significant difference in financial literacy, particularly in terms of behavior and attitude, attributed to variations in income patterns. Disparities in financial inclusion are observed concerning access, usage, quality, and well-being, stemming from geographical and systemic obstacles such as the coastal isolation of the blue economy and institutional barriers faced by both groups. The research concludes that financial literacy and financial inclusion play significant roles in influencing food security, with their effects varying across specific dimensions of each variable.

Keywords: financial literacy; financial inclusion; food security; green and blue economy

1. Introduction

In a world where millions struggle with hunger, financial literacy and inclusion may hold the key to unlocking food security for vulnerable populations. By 2023, 282 million people in 59 countries faced severe hunger—a grim 24 million increase from the previous year [1]. Adding to this crisis, food price inflation remains alarmingly high, with 48.8% of 166 countries surpassing global food price inflation levels in 2024. Addressing food security requires exploring the green and blue economies, two crucial sectors with the potential to combat hunger. In the green economy, agriculture serves as a lifeline, producing over 200 million metric tons of rice annually, the staple food for billions [2]. Beyond sustenance, agriculture fosters economic growth, reduces poverty, and generates jobs. Meanwhile, the blue economy, led by fisheries and aquaculture, provides livelihoods and nutrition to billions while tackling the challenge

of feeding a population projected to reach 9.6 billion by 2050 [3,4].

In the Philippines, food insecurity remains a critical concern. According to FAO, from 2019 to 2021, there were 5.3 million Filipinos that were severely food insecure. Moreover, fisherfolk and farmers persistently had the highest poverty rates from 2018 to 2021, with 30.6% and 30%, respectively [5]. These statistics highlight the ongoing challenges faced by agricultural and fishing households, which are disproportionately vulnerable to food insecurity. Limited incomes often compel these households to adopt coping mechanisms such as borrowing money, buying food on credit, or depleting savings [6]. One solution lies in enhancing financial literacy, the fusion of financial knowledge, skills, attitude and behaviors needed for informed decision-making. Financially literate individuals are better equipped to budget, save, and manage resources, reducing their risk of food insecurity [7,8]. In addition, financial inclusion refers to the effective access, usage, and quality of a variety of financial products and services tailored to enhance the financial welfare of individuals and enterprises, particularly those who are underserved or excluded by traditional financial systems [9]. While savings accounts significantly mitigate food insecurity, studies show that credit access alone is insufficient to address the issue [10].

Subsequently, 1836 belonged in the green economy, particularly rice farmers, and 1228 are in the blue economy, specifically fisherfolk that reside in San Jose, Camarines Sur, that depict a critical part in the economy in terms of livelihood and income. Green and blue economy is both a key player in San Jose, Camarines Sur, with a total rice farming area of 2198.56 ha and 7 barangays living in coastal areas (Tagas, Calalahan, Telegrafo, Manzana, Dolo, Sabang, and Adiangao). Therefore, it is vital to understand and integrate contemporary literature pertinent to the farming and fishing communities. This might be useful in determining possible issues. This study bestows guidelines for targeted actions to assist the growth of the green and blue sector in San Jose, Camarines Sur. The objectives of the study were to investigate the impact of financial literacy and financial inclusion on food security within the green and blue economies of San Jose, Camarines Sur, Philippines. Specifically, it aimed to achieve the following: 1) Describe the socio-demographic characteristics of respondents in terms of age, sex, civil status, educational attainment, landholdings, monthly income, years of farming and fishing, and household size. 2) Evaluate the level of financial literacy in the green and blue economies based on knowledge, skills, attitude, and behavior. 3) Assess the extent of financial inclusion in the green and blue economies regarding access, usage, quality, and welfare. 4) Determine the level of food security in the green and blue economies, considering availability, access, stability, and utilization. 5) Compare the levels of financial literacy, financial inclusion, and food security between the green and blue economies in San Jose, Camarines Sur. 6) Analyze how financial literacy and financial inclusion influence food security within the green and blue economies.

The study's results will be valuable to various stakeholders, including rice farmers and fisherfolk in San Jose, Camarines Sur, providing insights into financial literacy levels encompassing knowledge, skills, attitude, and behavior; financial inclusion regarding access, usage, quality, welfare, saving, credit, and insurance; and food security concerning availability, access, stability, and utilization. These findings will benefit the local communities by illuminating how financial literacy and inclusion impact food security and the well-being of farmers and fisherfolk. Local banks and

lending institutions can utilize the study's data to adapt their services responsibly, while the local government unit of San Jose can develop programs and policies aimed at supporting the agricultural and fishing sectors. Government agencies like the Department of Agriculture and the Bureau of Fisheries and Aquatic Resources can utilize the information to implement targeted programs, enhance data, and improve food security initiatives for farmers and fisherfolk. Partido State University can use the study's insights to inform their extension activities, and future researchers can reference this study when exploring similar topics related to financial literacy, financial inclusion, and food security among rice farmers and fisherfolk.

This study focuses on financial literacy, financial inclusion, and food security within the green and blue economies of San Jose, Camarines Sur. The qualitative relationships between financial literacy, financial inclusion, and food security are deeply interconnected. Financial literacy acts as a catalyst for financial inclusion, which in turn supports food security by enabling investments, risk mitigation, and resilience building. These relationships are particularly critical in the context of the green and blue economies, where sustainable practices and economic stability are essential for long-term food security. By addressing these linkages, our study provides valuable insights into how targeted interventions in financial literacy and inclusion can enhance food security in vulnerable communities. This qualitative relationship opens for inquiries to conduct causal-comparative research design to better understand correlation, causation, and differences. The inclusion of both the blue and green economies in our study is intentional, as it allows us to explore how financial literacy and inclusion operate in two distinct but interconnected economic contexts. The green economy focuses on sustainable agricultural practices, while the blue economy emphasizes sustainable use of marine resources. By comparing these two sectors, we aim to identify sector-specific challenges and opportunities for improving food security through financial literacy and inclusion [11–14].

The green economy includes registered rice farmers, and the blue economy comprises registered fisherfolk engaged in capture fishing. A total of 300 respondents are chosen using stratified random sampling. The research evaluates financial literacy (knowledge, skills, attitude, behavior), financial inclusion (access, usage, quality, welfare), and food security (availability, access, stability, utilization) among these groups. The goal is to analyze how financial literacy and inclusion impact food security for rice farmers and fisherfolk in San Jose. Findings are specific to this locale and may not be broadly applicable. San Jose, a fourth-class town in Camarines Sur, stands out for its significant rice farming and fishing activities, making it an ideal location for this study. Furthermore, the study intends to analyze the distinction and impact of financial literacy and financial inclusion on food security between the green and blue economies of San Jose, Camarines Sur. By serving as a framework for developing training programs and initiatives, it aims to enhance the financial knowledge and capabilities of farmers and fisherfolk, ultimately contributing to a more secure and sustainable future.

2. Review of related literature

The Philippines, a tropical country with diverse terrain, has a significant portion

of its population residing in rural areas and relying on agriculture for their livelihood. Approximately 25% of employed Filipinos are engaged in the agricultural sector, which includes farming, fisheries, livestock, and forestry [15]. These sectors, collectively forming the green and blue economies, are central to the rural population's sustenance. However, they face pressing challenges such as limited financial literacy and restricted access to financial services, which significantly impact food availability, access, stability, and utilization.

Financial literacy and financial inclusion are critical tools in addressing these challenges. Financial literacy is not a lack of finances, but rather a collection of information, skills, attitudes, and behaviors that enable individuals to better manage their resources. An inability to manage these resources frequently results in greater environmental shocks, lower savings, and poor economic management, making the people susceptible [7]. Financial inclusion, on the other hand, aims to improve the well-being of diabetes patients by promoting equal access to and use of financial services among disadvantaged populations [9]. It is clear that in areas where financial inclusion is fully integrated, the population is both economically stable and resilient.

Food security at the population level as a situation where most of the individuals are healthy and active, as it is easy for them to get enough nutritious food. It is examined within four dimensions: availability, access, utilization, and stability [16]. While there has been research looking at the connections between financial literacy and food security and food security and financial inclusion, more nuanced studies of these relationships in the green and blue economies and especially the local settings like San Jose, Camarines Sur, are few.

2.1. Financial literacy

Financial literacy is a combination of attitudes, skills and behaviors that give an individual the capability to make sound financial decisions so as to satisfy one's economic needs [7]. It requires acquiring the knowledge and skills that are needed for making good choices, such as the optimum of borrowed funds and the distribution of resources [17,18]. The research demonstrates that financially literate people have a propensity to behave better in decision-making in finance; otherwise, they do not engage in borrowing from costly lenders or do not leave funds idle. One can assert that these features in total mitigate the risk of loan default [19,20]. Since financial literacy brings awareness to the benefits of finances, it goes a long way in meeting the overall satisfaction levels and aids in meeting the requirements for effective economic management skills in budgeting and saving [21].

In addition to personal finance, financial literacy helps people understand the complexities of financial markets, evaluate investment alternatives, and make informed choices about retirement, insurance, and estate planning [21]. This knowledge is essential for long-term financial security and has a strong effect on overall well-being [22]. Additionally, financial literacy contributes to the broader economy, as individuals with better financial skills typically manage their resources better, make more informed and responsible spending decisions, and positively impact the overall economic well-being of society [7].

While financial literacy is essential, there are considerable gaps that exist—rice

farmers and fisherfolk, in particular. State of Households with Limited Financial Literacy and it indicates that households with limited financial knowledge are more likely to experience food insecurity [8]. According to Sanglay et al. [23], the distribution of income depends on educational levels and has an effect on whether someone is able to pay off debts, particularly for farmers who struggle to save money and erode it by overspending. Likewise, older male farmers may not emphasize the importance of finance management to save well since their priority is to satisfy family demand [23]. Other factors that influence financial literacy among farmers include age, education, and location relative to urban areas, income, and prior experience with financial education. Raza et al. [24] observed that, on average, financial literacy among farmers was moderate, shaped by these demographic and economic variables.

The results underscore the need for such kinds of farmer and fisherfolk-specific financial literacy programs in the Philippines. While certain economic research explores the broad impact of financial literacy on economic fragility, others zero in on the distinct struggles artisanal communities experience. Carman and Zamarro [8] explain a very simple relationship between food security and financial literacy as that the improvement in the financial literacy of farmers would help farmers secure food because the chances, they have that money to do it would improve. Similarly, Sanglay et al. [23] highlight the importance of education in debt management while implying that greater access to financial education could better equip farmers with respect to financial skills and reduce risk factors related to debt [23].

Financial literacy alone cannot play its part as the other influencer that would benefit a farmer and a fisherfolk on economic considerations of his welfare [25]. Also, provision to the aforementioned access means credit facilities and a deposit facility can greatly empower those members [26]. Moreover, it is essential to take into consideration the particular challenges they are exposed to, such as limited market access, volatile prices, and the effects of climate change, when developing programs on financial literacy and inclusion [27]. Addressing disparities in financial literacy is the only way towards achieving financial inclusion and economic improvement among farmers and fisherfolk. Investing in their financial education does, however, unlock their economic potential, thus nurturing resilience and creating a more equitable pathway to a better future.

Among farmers, sound financial knowledge enhances investment in agriculture, use of financial services, and increased productivity and food security [21]. Financial education investment maximizes the economic benefits of farmers, stabilizing food security, increasing household incomes, and reducing hunger in the communities where they live [17]. Inversely, low financial literacy increases the economic risk and puts the farmers on the back foot in responding to market shocks and coping with financial adversity [8]. A gain in financial literacy among rice farmers and fisherfolk needs to be considered for a shored-up economy of resilience and food security. The rise in financial literacy and capability will better equip them to fight against financial shocks that negatively influence anticipated life decisions [24,28].

2.2. Financial inclusion

Financial inclusion describes the effective access, usage, and various qualities of

financial services and products intended to support the progress of individuals and enterprises—including those traditionally left out of or poorly serviced by a formal financial arrangement. Such ensures that everyone, especially those considered vulnerable, can enjoy proper, high-quality financial service designed to meet needs such as savings, payments, credit, investments, and insurance [9]. Financial inclusion is the effort toward dismantling barriers that restrict access to finance so that everybody can have equal, affordable, and reliable financial products and services. This strategy enhances the access of such important services, such as savings, credit, payment, and insurance, for the people who lack collateral, stable employment, or an established credit history, hence aiding populations that have previously been excluded from the mainstream of the financial system [29].

The improvement of financial inclusion emerges as a major goal of international policy that can be accomplished through an enhancement of financial literacy. Financial literacy can enable people to make informative decisions, thereby slowly boosting their overall well-being [30]. An obvious relationship between financial literacy and financial inclusion exists since it facilitates several indirect benefits like cash management, purchasing power, account ownership, banking service access, and access to credit [31,32]. In addition, improving financial literacy is especially important for women because it enables them to use financial products and services effectively, which leads to better socio-economic outcomes [31,32].

Despite the development in financial inclusion, huge barriers remain. For example, financial inclusion can cut down the chance of insecurity about food mainly through facilities such as savings accounts. However, access to credit, which is one of the most highlighted tools in interventions targeting financial inclusion, would not be that effective to deal with food security concerns [31–33]. Moreover, food insecurity through financial services is subject to the kind of service; e.g., having an open savings account will significantly reduce the level of food insecurity, and reliance on credits is likely to increase the likelihood of developing food insecurity. The use of the formal payment service may reduce food security in a relatively marginal way [34].

To understand the connection between financial inclusion and food security in the Philippines, it's important to consider the country's unique challenges. Farmers and fisherfolk face issues like limited market access, price fluctuations, and climate change, making it hard to manage finances and ensure food security. Therefore, financial inclusion programs should be tailored to meet their specific needs, combining access to financial services with proper financial education and support [8].

Inclusive finance is about providing a wide range of affordable financial services to everyone, especially those who don't have access to formal financial systems. Financial literacy is the aspect on which the proper implementation of the services among individuals in the rural area depends. Improved financial inclusion equips disadvantaged people with adequate resources for their engagement in economic activities and contributes to upgrading living standards for further benefitting community progress. In summary, promotion of financial inclusion is significant for enabling the poor and other disadvantaged to access financial services necessary to enhance economic stability and food security [35]. However, financial inclusion in itself can do little to solve most economic and social problems; implementation requires consideration of the distinct needs of different communities so as to have a

more meaningful impact on livelihoods and food security.

2.3. Food security

Food security means that all people consistently have access to enough safe and nutritious food that meets their dietary needs for an active, healthy life [16]. Food security is evaluated across four main dimensions: Availability, access, utilization, and stability [16]. However, global hunger remains a significant issue, affecting almost 10% of the world's population. From 2019 to 2022, the number of people suffering from hunger increased by about 150 million [36]. In 2023, severe hunger levels rose to affect 282 million people in 59 countries, marking an increase of 24 million from the previous year [1]. Food price inflation also remains high, with 48.8% of 166 countries experiencing domestic food prices above the global inflation rate. The State of Food Security and Nutrition in the World 2023 report notes that while global hunger rates leveled off from 2021 to 2022, certain countries still face worsening hunger due to challenges such as post-COVID recovery, rising food and energy costs, conflicts, and adverse weather events.

In the Philippines, approximately 8.5% of the population faces undernourishment. Food insecurity can be categorized into chronic and transitory types [37,38]. Chronic food insecurity occurs when people consistently lack access to sufficient food over a long period, often due to poverty, limited resources, or underdeveloped systems. In contrast, transitory food insecurity is temporary, caused by sudden events like natural disasters, conflicts, or economic crises. While chronic insecurity requires long-term solutions like improving education and agriculture, transitory insecurity needs immediate responses such as food aid or emergency relief.

To meet global food demand, sustainable food supply chains, particularly those relying on coastal communities and environmentally friendly food production, are essential. Marine resources play a significant role in global food security, accounting for two-thirds of fishery production and 80% of aquaculture production. Additionally, the number of fish available to the population in coastal areas is 65% above the global average [39]. Agricultural sectors have a significant role in attaining SDGs by achieving food security, poverty alleviation, and nutrition enhancement, which subsequently leads to child mortality rates declining.

The concepts of financial literacy and inclusion are essential toward building food security. Financial inclusion means that people have access to savings and credits, which enables them to maximize resources and ensure stable provisions for their households in the short run. In contrast, financial literacy builds the knowledge that persons acquire in making proper choices toward improving their access and, consequently, capacity toward getting food. Savings accounts can significantly reduce food insecurity, whereas relying solely on credit would not have any similar effects [10]. Moreover, the type of financial service used matters; when discussing food security, savings accounts can significantly reduce food insecurity, whereas reliance on credit may increase it, and formal payment services have little to no effect [34].

Food security affects agricultural producers and fishery workers in distinct ways, attributable to the specific challenges inherent in their roles. Particularly for those situated in rural regions, farmers play a critical role in enhancing food security through

the cultivation of crops that are vital for local and national food supplies. For any developing country, the agriculture sector plays a very strategic role in ensuring food security. It does this either directly through income generation or through employment and nutrition, hence achieving the SDG set out by Geng et al. [40]. Challenges to farmers include, but are not limited to, climate change and volatile markets, which impact food security.

Fisherfolk form an important group in coastal regions' food supply chains. Marine resources are vital for global food security as they provide a big portion of the world's fish and aquaculture products. Coastal communities heavily dependent on these marine resources contribute enormously to the supply of the world's fishes. The communities of fisherfolk have specific challenges related to environmental degradation, overfishing, and climate change that carry risks to food availability and stability. Therefore, sustainable policies and practices that promote financial inclusion for fisherfolk are crucial to maintaining their role in food security. In conclusion, there is a need to devise strategies that cater to the needs of both farmers and fisherfolk with regard to food security. Financial literacy and inclusion will improve food security through sustainable livelihoods and long-term access to food for these communities [39,40].

2.4. Green and blue economies

The green and blue economies are crucial for promoting sustainable development in rural areas, each with distinct yet complementary roles. The green economy focuses on sectors such as agriculture, forestry, renewable energy, and waste management, promoting practices that support environmental sustainability, economic growth, and community well-being [41]. Through the green economy, agriculture is the key sector [42]. As it caters to the world by serving as a primary source of income for many individuals and provides global nutrition. Particularly the rice farmers, which yield over 200 million metric tons of rice, which is considered to be a staple food to people. Additionally, it supports GDP growth, guides the way in poverty reduction, and provides a broad range of job possibilities [42,43]. Rice farming provides a stable but modest income to farmers, contributing significantly to food security; however, these farmers face challenges such as limited capital, fluctuating productivity, and vulnerability to climate risks [44]. Agriculture remains one of the largest sources of employment worldwide, engaging approximately 37% of the global workforce, with the majority located in developing countries. This makes the agricultural sector a critical driver of economic development and poverty alleviation in rural regions [45,46].

The blue economy is a critical component in providing nutrition to billions of people [4]. The fisheries and aquaculture industry is a key driver of livelihoods, nutritious food, and economic opportunities, and it serves an essential role in addressing one of the world's major difficulties: feeding a population projected to reach 9.6 billion by 2050. Fisheries and aquaculture play an important role in stopping hunger, improving health and reducing poverty. This method is very important for improving food security along with creating income in coastal as well as rural communities [47]. Fisheries, a foundation of the blue economy, support the livelihoods

of millions of people and are very important for meeting the increasing global demand for food as populations continue to grow. Small-scale fishers are important; however, they are frequently left out of important policy discussions about the blue economy. This important absence of representation can result in the serious neglect of their large social and economic needs, despite their playing an analytically important role in supplying affordable, nutritious food to communities worldwide [48].

The green and blue economies have to respond to challenges posed by environmental and economic changes, such as climate change, depletion of natural resources, and financial instability. The agricultural sector within the green economy faces very serious climate change-related vulnerabilities that usually affect smallholder farmers who do not have adequate resources for adaptation. Such initiatives reduce the risk of climate change, and simultaneously strengthen food security. A portion of agricultural households suffer severe food insecurity, thus having to resort to coping mechanisms, such as taking credit or tapping into savings to ensure their basic needs are met [49].

Fisheries and aquaculture are vulnerable to ecosystem disruptions by which unsustainable practices have caused the reduction of marine biodiversity, food supply, and the decline in the livelihoods that depend on them. The sustainable blue economy seeks to preserve the marine environment for the long-term benefit of communities [47]. Small-scale fisher organizations argue for resilient policies, claiming that industrial activities often harm coastal communities and food security [47,48].

Fishermen face declining fish stocks and limited access to formal banking institutions, impeding progress toward sustainable investment. Likewise, rice farmers are equally enmeshed in deep financial ignorance as it relates to their ability to put savings, credit, and other safe investments into practice, hence preventing communities from cushioning themselves against economic shocks [44]. Fisherfolk use informal lending institutions as a means to obtain credit; this ultimately increases their financial vulnerability [23,44].

These ubiquitous challenges, therefore, imply the need for targeted financial education and inclusion programs. Tools such as mobile banking and financial literacy training are aimed at improving financial behaviors that would enhance economic stability and food security. Despite climate disruptions affecting rice farming, fisheries also suffer from resource depletion and inefficiencies throughout the supply chain [50,51].

Rice farmers have operational seasonal incomes that fuel predictability in contrast to fisherfolk, who often base their livelihoods on unpredictable daily catches, hence distinguishing their saving and investment behaviors. Distinguishing these characteristics signifies that present-day policies encourage community involvement, value chain strengthening, and customized financial incentives. Organizations like the World Bank have been advocating for integrated approaches toward fostering sustainable development in both green and blue economies [52].

2.5. Financial literacy, financial inclusion, and food security

A comparison of green and blue economies points out major challenges regarding the issues of financial literacy, inclusion, and food security within rural settings.

Financial literacy provides people with information and skills to enable them to make informed financial choices, access credits, and invest in sustainable practices that improve resilience. In the green economy, financially literate farmers are able to embrace technologies that raise productivity, reduce food insecurity, and ensure financial security [51–54].

In contrast, for the blue economy, financial inclusion is particularly important since small-scale fishers often lack access to formal financial services. This will help them to be financially literate and included in budgeting their earnings, borrowing to procure sustainable gear, and undertaking activities that protect marine ecosystems. Thus, such measures will stabilize the incomes of fishers and support food security by providing access to affordable and nutritious fish in coastal areas [55]. Yet more often than not, the small-scale fishers are excluded from blue economy policies, thus placing constraints on their access to much-needed finances or the ability to render support to them [48].

In both economies combined, financial literacy and inclusion involve providing better food security, resilience, and overall economic growth within rural communities. Financial literacy helps farmers and fishers with budgeting, resource-wise allocation, and viability in a way that contributes to household food security [53,54,56,57]. Financial inclusion plays a complementary role in providing access to financial services to enable them investments for productivity, accumulation of savings, and resilience to economic shocks [30,31]. Financial literacy and inclusion studies indicate that households with financial literacy and inclusion are more capable of ensuring consistent food availability, or improving diet and nutrition, and are more empowered to meet financial needs [58–61] Green and blue economies are of utmost importance to San Jose, Camarines Sur, since the livelihood of farmers and fisherfolk is very vital for the sustainability of practices. Farmers working in the green economy play a huge role in promoting sustainable agriculture practices, protecting biodiversity, and reducing carbon emissions [62]. Meanwhile, the blue economy stresses the responsible use of marine resources, with fisheries and aquaculture as key players in food supply, poverty alleviation, and job creation [47,48]. While these sectors have very different operational philosophies from each other, they, however, have similar challenges regarding food security, financial management, and adaptation to environmental changes, making financial literacy and financial inclusion an ever-greater need.

This tells where this study attempts to bridge some gaps in the literature with an assessment of financial literacy and inclusion affecting food security specifically among rice farmers and fisherfolk of San Jose, Camarines Sur. The researches before laid emphasis on these variables, yet the effect of their combination in these two sectors regarding food security has never been examined. In addition, this study will give insight into the peculiar needs and issues faced by rice farmers and fisherfolk from which identified financial interventions can be tailored to meet specific needs to improve food security under the green and blue economies. The final objective is to draw policies for financial education and inclusion that can best tackle food insecurity in rural agricultural and fisheries contexts, leading to sustainable economic development in the region.

2.6. Frameworks

The theory pertaining to the research that explains financial inclusion, financial literacy, and food security is introduced and described in **Figure 1**. Financial Literacy Theory of Financial Inclusion, Capability Theory, and Entitlement Theory were used in research.

The financial literacy theory of financial inclusion [63] points out the role of education in promoting formal financial service use. Increased financial literacy increases awareness of services and leads to account openings and access to products such as investments and mortgages. It also helps cash-strapped governments since educating citizens is a low-cost way of promoting financial inclusion. However, it focuses on increasing people's willingness to use financial services but not their capacity, the financial resources needed to actively participate in the formal financial sector.

Amartya Sen's Capability Theory gives emphasis to freedom for individuals and the capabilities that enable them to achieve a life they value [64]. In finance, it is translated to financial capability, combining internal factors like knowledge, skills, and behaviors with external opportunities in the form of access to financial systems [64,65]. This theory is closely related to financial inclusion, which provides for external opportunities in terms of credit, savings, and other financial services that support the accomplishment of goals for individuals. While financial literacy represents internal abilities, financial inclusion reflects external opportunities, and together, it empowers individuals to manage their finances effectively [66].

Entitlement Theory, which was also developed by Amartya Sen, suggests that people's capacity to acquire food is determined by their entitlements, the legal means and opportunities available to them [64]. This approach focuses on access to food rather than its availability, arguing that food security is determined by entitlements such as growing food, trading goods or services, earning wages, or receiving aid [67]. Food insecurity is the condition created by entitlement failure due to an economic shock, social inequality, or political challenge. Thus, this theory claims that food security and entitlement theory are inherently interconnected.

The qualitative relationships between financial literacy, financial inclusion, and food security are interconnected and mutually reinforcing. This relationship compels authors to conduct empirical analysis to validate these insights and intuitions. Financially literate individuals better understand the benefits of formal financial services, such as savings accounts, credit facilities, and insurance products. This knowledge encourages them to actively seek and utilize these services, increasing their level of financial inclusion. Low financial literacy often acts as a barrier to financial inclusion. Individuals lacking financial knowledge may distrust formal financial institutions, prefer informal mechanisms (cash savings or informal lenders), or make suboptimal financial decisions. By improving financial literacy, these barriers can be reduced, leading to greater financial inclusion.

Financial inclusion enables individuals like farmers and fishermen to access credit for purchasing inputs (seeds, fertilizers, fishing gear) or investing in productivity-enhancing technologies. It also provides access to insurance products that protect against risks such as crop failure, natural disasters, or health emergencies.

Access to savings accounts allows households to build financial reserves for purchasing food during scarcity or economic hardship, creating resilience particularly important for vulnerable rural populations. Financial literacy both directly and indirectly influences food security by empowering individuals to make better financial decisions that enhance economic stability and food access. Financially literate individuals can allocate resources more effectively, ensuring they can afford nutritious food even during financial strain. This literacy enables informed decisions about agricultural or fishing investments, which can increase productivity and income. Financially literate individuals are more likely to be aware of and utilize financial services supporting food security, such as microloans for small-scale farming or government subsidies for agricultural inputs. Thus, improved financial literacy leads to greater financial inclusion through increased awareness and usage of formal financial services. Financial inclusion enhances food security by providing access to credit, insurance, and savings, enabling households to invest in productive activities, manage risks, and build resilience. Households achieving food security are better positioned to invest in financial literacy programs and participate in formal financial systems, creating a positive feedback loop. Financial literacy enables farmers to adopt sustainable agricultural practices, while financial inclusion provides necessary resources (credit for organic fertilizers or irrigation systems) to implement these practices, improving agricultural productivity and food security. Similarly, financial literacy helps fishermen understand the importance of sustainable fishing practices, while financial inclusion provides access to credit for modern equipment or insurance against environmental losses, contributing to stable incomes and improved food security. These interrelatedness and complexities were illustrated by the theoretical paradigm as shown in **Figure 1** [49,68–71].

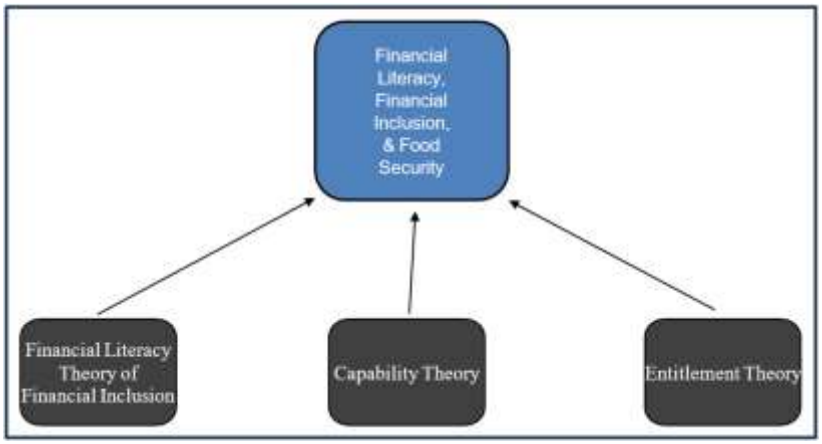

Figure 1. Theoretical paradigm.

Conceptual framework

Figure 2 shows the overall process of this study, with a specific emphasis on three variables. The first factor is financial literacy, which serves as the independent variable and consists of four indicators: knowledge, skills, attitude, and behavior. The second factor is financial inclusion, which also acts as the independent variable and also encompasses seven indicators: access, usage, quality, and welfare. The food security will serve as a dependent variable that comprises four dimensions: Availability,

access, utilization, and stability. The diagram aims to assess the impact of financial literacy and financial inclusion on food security by evaluating each of these indicators. To put it differently, the diagram illustrates the process of measuring how financial literacy and financial inclusion influence food security through an analysis of these indicators.

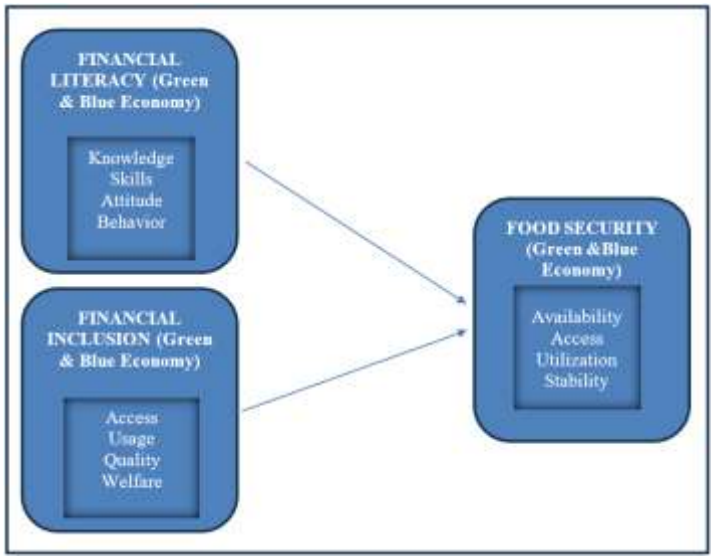

Figure 2. Conceptual paradigm.

3. Research methods

3.1. Research design

This research used a causal-comparative research design to assess the socio-demographic profile, examine the level of financial literacy, financial inclusion, and food security, evaluate the comparative differences in the level of financial literacy, financial inclusion, and food security between the green economy and blue economy, and analyze the extent of influence of financial literacy and financial inclusion on food security among rice green and blue economies in San Jose, Camarines Sur.

3.2. Sampling design

The research utilized a random sampling technique where populations will be the same as to select. The researchers utilized a stratified random sampling formula to easily get the data.

$$nh = (Nh/N) \times n,$$

where:

nh = sample size stratum, n = sample size;

N = population size;

Nh = population size stratum.

3.3. Respondents of the study

In this study, 1836 registered rice farmers and 1228 registered fisherfolk in San Jose, Camarines Sur. Using the stratified sampling formula, 180 and 120 were the

respondents in San Jose, Camarines Sur, accordingly. This entails demonstrating the purpose, procedures, and benefits to the participants in order to secure their voluntary consent to partake in the study.

3.4. Locale of the study

The town of San Jose is in Camarines Sur is shown in **Figure 3**; as of the 2020 census, it is classified as a fourth-class town. The municipality occupies 0.87% of Camarines Sur's total area, or a land area of 48.04 square kilometers. According to consensus, by 2020 the town has a population of 43,973. Moreover, based on the data from the Department of Agriculture, the locale has the most physical area of rice paddy and farmers among the municipalities of Partido. Subsequently, its rice field has an area of 2198.56 hectares with 1836 registered farmers. Additionally, 7 out of 28 barangays are living in coastal areas (Tagas, Calalahan, Telegrafo, Manzana, Dolo, Sabang, and Adiangao), consisting of 1228 registered fisherfolk, and it is the only town among Partido that is connected to the seaside area. Thus, San Jose, Camarines Sur, is the chosen locale for the study [72].

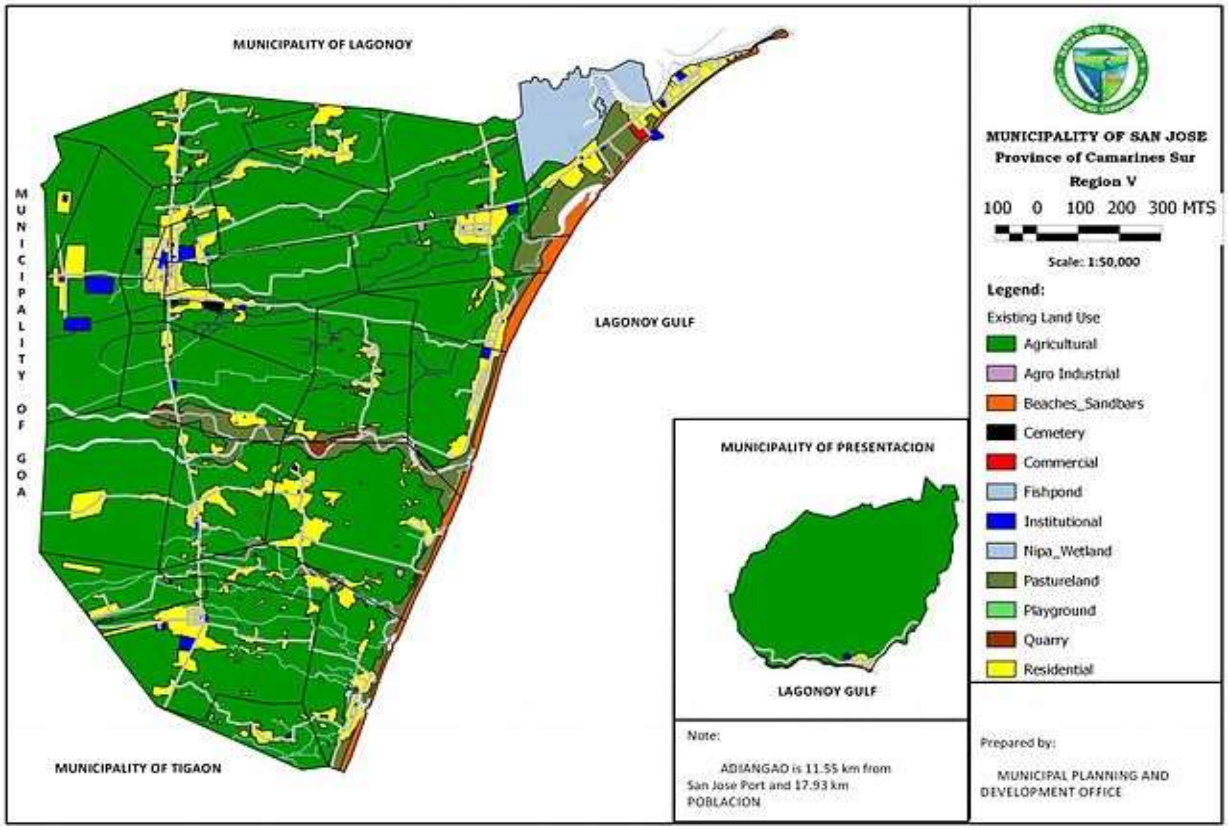

Figure 3. Map of San Jose, Camarines Sur, Philippines (LGU San José, 2024).

3.5. Data gathering procedures

The letter of request was distributed, and the questionnaire was administered in San Jose, Camarines Sur. Following a letter of approval, request permission and gather the relevant information. Prior to being distributed to the target individuals, the questionnaire will be verified for reliability and validity. The researchers administered the questionnaires during the gathering procedure. Measures were taken to ensure that

ethical norms are followed throughout the study process. The questionnaire is divided into three parts based on the participant's perception.

3.6. Data gathering tools

The researchers applied survey questionnaires in data gathering. The survey questionnaires had been validated by three credible validators. Before the actual data collection, a pilot test was first undergone in Sagñay, Camarines Sur, that has green and blue economies present. To test its reliability, Cronbach's alpha was utilized; a score of more than or equal to 0.7 indicates that the response value for each respondent across a set of questions is consistent. The result of Cronbach's alpha is 0.739; hence, the data are reliable. The first part (I) focused on obtaining the socio-demographic information of the rice farmers and fisherfolk, including age, sex, civil status, educational attainment, landholding (ha), monthly income, and years of farming/fishing. The second part determined the level of financial literacy in terms of knowledge, skills, attitude, and behavior. The third part assesses the level of financial inclusion regarding access, usage, quality, welfare, saving, credit, and insurance. The fourth part ascertains the level of food security in terms of availability, access, stability, and utilization.

3.7. Statistical/analytical tools

To answer the objectives, the following analytical tools were used (See **Table 1**).

Percentage Technique. This instrument was utilized to measure the socio-demographic of the respondents.

$$\text{Technique: } P = \frac{F}{N} \times 100,$$

where:

P = percent;

f = frequency;

N = number of cases.

Weighted Mean. This tool was used to compute the Likert scale ranging from strongly agree = 5 to strongly disagree = 1, to determine the tendency of composite scores.

$$W = \frac{\sum_i^n = 1 w_i x_i}{\sum_i^n = 1 w_i},$$

where:

W = weighted average;

n = number of terms to be averaged;

ωi = weight value;

xi = data value to be averaged.

The study employed a Likert scale, with each point corresponding to the following verbal interpretations.

Table 1. Likert scale.

Likert Scale	Verbal Interpretation
4.21–5.00	Strongly Agree
3.41–4.20	Agree
2.61–3.40	Not Sure
1.81–2.60	Disagree
1.00–1.80	Strongly Disagree

Kruskal-Wallis Test. This tool is employed to ascertain whether there exist statistically significant disparities between two or more groups of an independent variable on a continuous or ordinal dependent variable.

$$H = \frac{12}{NN+1} + \Sigma\frac{R_i^2}{n_i} - 3N + 1,$$

where:

N = Total number;

n_i = The number in the i-th group;

R_i = Total sum of the ranks in the i-th group.

Multivariate Linear Regression. This tool is utilized to examine the linear influence of multiple variables of financial literacy and financial inclusion on food security.

$$Y = b0 + b1 \times 1 + b1 + b2 \times 2 + \cdots + bp \times p,$$

where:

Y = Food Security (Availability, Access, Stability, and Utilization);

b_0 = Intercept, the expected value of Y when all independent variables are equal to zero;

b_1, b_2, ..., b_p = Coefficients (indicate the change in Y for each one-unit increase in the corresponding X-variable, holding others constant);

X_1 = Financial Literacy indicators (Knowledge, Skills, Attitude, and Behavior);

X_2 = Financial Inclusion indicators (Access, Usage, Quality, and Welfare);

X_3, ..., X_P = Control variables (e.g., income level, household size, education, or other factors that might influence food security).

4. Results and discussions

4.1. Socio- demographic of green economy and blue economy

This section presents the socio-demographic profile of the Green Economy and Blue Economy of San Jose, Camarines Sur that encompasses age, landholdings, monthly income, years of farming/fishing, household size, sex, civil status, educational attainment.

Table 2 shows the socio-demographic profile of the two groups. The blue economy has the lowest age of 21 years old, while the oldest in the green economy is 85 years old. In the land holdings, the green economy has the largest land owned of 7 hectares, while the lowest is the blue economy, which is 0. Similarly, their monthly income also has the highest amount, ranging from 1000 to 61,000. As to the blue

economy, only extend from 1000 to 20,000. In terms of years of farming/fishing and household size, the green and blue economy results are not far apart, with 60 and 58 years and 14 and 12 family members, respectively. The majority of the respondents, whether in the green and blue economy, are male, with 63.9% rice farmers and 80% fisherfolk. Most of the respondents are married, with 77.2% rice farmers and 69.2% fisherfolk; the next highest is other (live-in) with 11.7% rice farmers and, for the fisherfolk, is single with 16.7%. Moreover, a large portion of the respondents have an educational attainment of high school level, 41.7% for the rice farmers and 44.2% for the fisherfolk. However, in terms of college graduates, the green economy has a higher number of 13.9% than the blue economy of only 1.7%.

Table 2. Socio-demographic profile of green economy and blue economy.

Socio-Demographic Characteristics	**Green Economy**		**Blue Economy**	
	MIN	**MAX**	**MIN**	**MAX**
Age	25	85	21	75
Landholdings	0.25 ha	7 ha	0	1 ha
Monthly Income	1000	61,000	1000	20,000
Years of Farming/Fishing	1	60	1	58
Household Size	1	14	1	12
	Frequency	Percentage	Frequency	Percentage
Sex				
Female	65	36.1	24	20.0
Male	115	63.9	96	80.0
Civil Status				
Married	139	77.2	83	69.2
Single	20	11.1	20	16.7
Divorced	0	0	1	0.8
Others	21	11.7	16	13.3
Educational Attainment				
Elementary Level	20	11.1	18	15.0
Elementary Graduate	34	18.9	23	19.2
High School Level	75	41.7	53	44.2
High School Graduate	8	4.4	23	19.2
College Level	17	9.4	1	0.8
College Graduate	25	13.9	2	1.7
Others:	1	0.6	0	0

The Green Economy demonstrates clear advantages in socio-demographic indicators, particularly landholdings and income. Green Economy participants own larger land plots (0.25–7 hectares), enabling higher income generation (up to ₱61,000 monthly), compared to the Blue Economy, where limited or no landholdings (0–1 hectare) constrain earnings (up to ₱20,000 monthly). Both groups have similar household sizes and years of experience in farming or fishing, yet gender roles reflect cultural norms. Men dominate labor-intensive activities, while women contribute to

post-harvest work and household food security [73].

Educational attainment differs significantly, with only 1.7% of Blue Economy participants being college graduates compared to 13.9% in the Green Economy. The Green Economy's higher income is primarily attributed to larger landholdings and higher educational attainment. Individuals earning ₱60,000 to ₱61,000 monthly typically own at least 2 hectares of land and earn additional income from other sources, supported by their higher rate of college education. In contrast, the Blue Economy's smaller landholdings, lower income, and limited education exacerbate poverty risks, aligning with national statistics showing fisherfolk have the highest poverty incidence among rural workers [5,74,75].

4.2. Level of financial literacy of green economy and blue economy in San Jose, Camarines Sur

This section assesses the level of financial literacy among the Green Economy and Blue Economy in San Jose, Camarines Sur, based on their knowledge, skills, attitude, and behavior.

Table 3 presents the average weighted mean of the four indicators of financial literacy. The average weighted mean regarding knowledge for green economy is 4.00 that interpret to agree and for blue economy is 4.13 that is equivalent to agree. With regards to skills, the average weighted mean for green economy is 3.46 indicating an agree interpretation, meanwhile for blue economy is 3.35 that shows a not sure interpretation. As to attitude, the average weighted mean is 3.35 for the green economy and 3.38 for the blue economy, which both result in a not-sure interpretation. Moreover, the behavior of the green and blue groups resulted in an agreement interpretation with values of 3.53 and 3.45, respectively.

Table 3. Level of financial literacy (in terms of knowledge, skills, attitude, and behavior) between green and blue economies.

Knowledge	**Green Economy**		**Blue Economy**	
	Weighted Mean	**Verbal Interpretation**	**Weighted Mean**	**Verbal Interpretation**
Knowledge on interest rates.	3.67	Agree	3.73	Agree
Knowledge on inflation.	3.75	Agree	3.98	Agree
Knowledge on time value of money.	3.92	Agree	4.11	Agree
Knowledge on income and expenditure.	4.47	Strongly Agree	4.58	Strongly Agree
Knowledge on Risk and Return.	4.21	Strongly Agree	4.26	Strongly Agree
Average Weighted Mean	4.00	Agree	4.13	Agree
Skills				
Skills to regularly track its income and expenses.	4.22	Strongly Agree	4.28	Strongly Agree
Skills to have an emergency fund that can cover 3–6 months of expenses.	2.78	Not Sure	2.85	Not Sure
Skills to recognize a good financial investment.	4.09	Agree	4.05	Agree
Skills to make good decisions involving money.	3.08	Not Sure	2.57	Disagree
Skills to understand financial information.	3.12	Not Sure	3.01	Not Sure
Average Weighted Mean	3.46	Agree	3.35	Not Sure

Table 3. (*Continued*).

Knowledge	Green Economy		Blue Economy	
	Weighted Mean	**Verbal Interpretation**	**Weighted Mean**	**Verbal Interpretation**
Attitude				
Attitude that setting financial goals for the future is important.	4.67	Strongly Agree	4.68	Strongly Agree
Attitude that managing their money affects the future.	4.24	Strongly Agree	4.28	Strongly Agree
Attitude that saving money is more satisfying than spending.	3.17	Not Sure	3.34	Not Sure
Attitude that money is not made to be spent.	1.54	Strongly Disagree	1.23	Strongly Disagree
Attitude that saving is possible for their family.	3.12	Not Sure	3.35	Not Sure
Average Weighted Mean	3.35	Not Sure	3.38	Not Sure
Behavior				
Behavior of making notes and controlling their spending.	4.24	Strongly Agree	4.58	Strongly Agree
Behavior of not asking family or friends to borrow money to pay bills.	2.22	Disagree	1.79	Strongly Disagree
Behavior of not spending more money than they earn.	1.79	Strongly Disagree	1.32	Strongly Disagree
Behavior of analyzing bills before making a large purchase.	4.62	Strongly Agree	4.82	Strongly Agree
Behavior of comparing prices when making a purchase.	4.80	Strongly Agree	4.75	Strongly Agree
Average Weighted Mean	3.53	Agree	3.45	Agree

Financial literacy in the Green Economy appears to be slightly stronger overall, particularly in terms of skills and knowledge. This advantage aligns with their more predictable income cycles and larger educational attainment compared to the Blue Economy. The Blue Economy, however, lags behind in skills, interpreted as not sure, likely reflecting the income variability caused by seasonal and weather-dependent fishing activities.

The similarities in attitudes across both groups suggest shared beliefs about financial management, including the importance of setting financial goals. However, there is a notable division in their ability to save money, with some individuals prioritizing spending for immediate satisfaction over saving for the future.

Both groups showed positive behavior, like spending control, tracking expenses, and comparing prices before purchasing. However, despite having this behavior, they demonstrate a harmful behavior of spending above their income, which is due to their irregular income patterns.

The results demonstrate that financial literacy in both economies is determined by their socioeconomic context. Higher education and predictable cycles of agricultural income towards the Green Economy also help, promoting financial literacy. Farmers can organize the spending of their income around harvest seasons and develop better financial judgment and budgeting habits [23,76,77].

On the other hand, the Blue Economy encounters problems like irregular and seasonal income based on weather and daily catches. The reduced confidence in financial skills indicates the challenges of fisherfolk in managing fluctuations in their income. Nevertheless, in a study, those with higher financial literacy are well equipped to plan saving strategies and utilize credit services to settle these challenges [5,78,79]

The result showed that both groups lack emergency funds, which emphasizes

their vulnerability to financial shocks. Individuals with limited or unstable income rely on meeting day-to-day requirements rather than building up any kind of protective buffer [48,76,77].

Older male farmers tend to address first their family needs, which results in prioritizing spending over saving, which describes this continual behavior of both economies [23,78–80].

The results are similar to the studies on financial literacy and income stability in rural economies. Recent studies highlight that a person with financial knowledge is decisive, utilizing loans, investments, and savings, which are components in managing risks. Evidently, the green and blue economies do not possess these financial practices and lack the ability to make a well-decided loan [23,81].

Moreover, seasonal income variability amongst fisherfolk can be managed through financial literacy [5]. Increased financial literacy enables fisherfolk to save, borrow and adjust to inflationary impacts on the costs of production [82,83]

4.3. Level of financial inclusion of green economy and blue economy in San Jose, Camarines Sur

This section assesses the level of financial inclusion among the Green Economy and Blue Economy in San Jose, Camarines Sur, based on their access, usage, quality, and welfare.

Table 4 exhibits the average weighted mean of the level of financial inclusion with its four indicators. In terms of access, the green economy has an average of 3.25 and the blue economy has an average of 2.65, which both indicate a not-sure interpretation. Regarding usage, both groups have the same verbal interpretation of not, but the different value for the green economy is 3.38 and for the blue economy is 3.07. The quality for green economy results is 3.78, which is agreeable, and for blue economy results, it is 3.61, which is also agreeable. For the welfare, both have a verbal interpretation of strongly agree, with a value of 4.55 for the green economy and 4.63 for the blue economy.

Table 4. Level of financial inclusion (in terms of access, usage, quality and welfare) between green and blue economies.

Financial Inclusion	**Green Economy**		**Blue Economy**	
Access	**Weighted Mean**	**Verbal Interpretation**	**Weighted Mean**	**Verbal Interpretation**
Access to banks is easy.	2.92	Not Sure	1.80	Strongly Disagree
Access to microfinance is easy.	3.39	Not Sure	2.86	Not Sure
Access to applying for insurance is easy.	3.62	Agree	2.87	Not Sure
Access to financial products designed specifically for Green/Blue Economy is available.	3.23	Not Sure	2.91	Not Sure
Access to mobile banking or e-wallets (e.g., GCash, Paymaya) is easy.	3.09	Not Sure	2.83	Not Sure
Average Weighted Mean	3.25	Not Sure	2.65	Not Sure

Table 4. (*Continued*).

Financial Inclusion	**Green Economy**		**Blue Economy**	
Access	**Weighted Mean**	**Verbal Interpretation**	**Weighted Mean**	**Verbal Interpretation**
Usage				
Usage of financial institutions like banks, pawnshops, or remittance centers is common.	3.33	Not Sure	3.00	Not Sure
Usage of savings accounts in the bank is practiced.	1.99	Disagree	1.41	Strongly Disagree
Usage of loans from financial institutions is preferred over Five-six moneylenders.	4.25	Strongly Agree	4.03	Agree
Usage of financial services for sending or receiving remittances is evident.	3.63	Agree	3.38	Not Sure
Usage of insurance (health, life, accident, or non-life) is evident.	3.69	Agree	3.53	Agree
Average Weighted Mean	3.38	Not Sure	3.07	Not Sure
Quality				
Quality of the transaction process in banks is satisfactory.	3.45	Agree	3.36	Not Sure
Quality of information about financial transaction fees comes from notices, flyers, brochures, bank staff, or word of mouth.	3.56	Agree	3.27	Not Sure
Quality of transactional fees is considered fair.	4.18	Agree	4.15	Agree
Quality of loan interest rates in financial institutions is acceptable.	4.37	Strongly Agree	4.26	Strongly Agree
Quality of service includes offerings of financial products like insurance, savings, or loans.	3.34	Not Sure	3.03	Not Sure
Average Weighted Mean	3.78	Agree	3.61	Agree
Welfare				
Welfare is enhanced by access to financial services and products, which is considered important.	4.54	Strongly Agree	4.78	Strongly Agree
Welfare is supported by the belief that saving is important.	4.82	Strongly Agree	4.91	Strongly Agree
Welfare is linked to the importance of opening savings accounts.	4.68	Strongly Agree	4.72	Strongly Agree
Welfare is significantly impacted by borrowing money, which is considered essential.	4.15	Agree	4.06	Agree
Welfare does rely on insurance, as it is viewed as necessary.	4.55	Strongly Agree	4.69	Strongly Agree
Average Weighted Mean	4.55	Strongly Agree	4.63	Strongly Agree

Both the Green Economy and Blue Economy face challenges in accessing formal financial services, primarily due to geographical constraints [48]. Small-scale fishers, particularly in remote coastal areas, experience greater difficulties compared to rice farmers. While the Green Economy has better insurance coverage, often through bundled loans offered by lending institutions, the Blue Economy remains hesitant about insurance due to affordability concerns linked to their unpredictable income cycles [23,76].

Neither group maintains savings in banks, which can be attributed to limited financial literacy, lack of trust in formal systems, and perceptions of high costs or inaccessibility [30,35]. Both groups avoid predatory five-six moneylenders and prefer microfinance services instead, reflecting a cautious approach toward borrowing [29]. However, insurance coverage across both economies is not out of personal choice, but as a mandatory inclusion by the lending companies they depend on for loans. This

indicates a lack of active engagement or interest in insurance itself, as it is viewed more as a default feature rather than a valued financial tool.

Satisfaction with financial services also varies. The Green Economy reports greater satisfaction due to better familiarity and access, while the Blue Economy cites slow processes, excessive requirements, and geographic isolation as key barriers. Both groups find interest rates burdensome, though manageable, due to their irregular income patterns, seasonal for rice farmers and unstable for fisherfolk [10,30,76].

Despite these challenges, both economies recognize the value of financial services for stability and security. They recognize the significance of savings, insurance and availing on loans during financial emergencies. However, their dependence on credit emphasizes their financial vulnerability.

The data shows both the green and blue economies have financial inclusion issues, especially when it comes to accessing and using formal financial services. Although the green economy has better access and quality, they are not susceptible to financial literacy gaps that are not equipped for making savings, investment, and loan decision-making. In contrast, the blue economy faces more obstacles to access and usage, which are driven by geographic isolation and irregular income.

Both economies demonstrate a financial vulnerability, as they don't have savings and active insurance engagement. Thus, it suggests that even if financial products and services exist, there are still hindrances, such as affordability, accessibility, and trust, that prevent both groups from having active participation.

Furthermore, both groups showed a dependence on loans, most especially in times of financial distress. This highlights their reliance on credit rather than proactive financial planning. The dissatisfaction expressed by the Blue Economy highlights systemic inefficiencies that need addressing to improve access and trust in formal banking systems.

4.4. Level of food security of green economy and blue economy in San Jose, Camarines Sur

This section assesses the level of food security among the Green Economy and Blue Economy in San Jose, Camarines Sur based on their availability, access, stability and utilization.

Table 5 reveals the average weighted mean of the four indicators of food security. The food availability for the green economy is 3.46, and for the blue economy, it is 3.41, which both equal to agree. The food access for the green economy is 3.26, and for the blue economy is 2.74, which both indicate not sure. The food stability of both groups has the same verbal interpretation of not sure, with a value of 3.23 for the green economy and 3.40 for the blue economy. The food utilization both have a strongly agree interpretation with a result of 4.30 for the green economy and 4.23 for the blue economy.

Table 5. Level of food security (in terms of availability, access, stability and utilization) between green and blue economies.

Food Security	**Green Economy**		**Blue Economy**	
Availability	**Weighted Mean**	**Verbal Interpretation**	**Weighted Mean**	**Verbal Interpretation**
Availability of food is sufficient to meet the needs of the family.	4.73	Strongly Agree	4.67	Strongly Agree
Availability of balanced meals, including meat, fish, vegetables, and rice, is within the household's means.	4.59	Strongly Agree	4.68	Strongly Agree
Availability of food is not a concern, as the household didn't worry about not having enough to eat.	2.23	Disagree	1.84	Disagree
Availability of food is adequate, and always the types the household prefers.	2.27	Disagree	2.47	Disagree
Average Weighted Mean	3.46	Agree	3.41	Agree
Access				
Access to the market to purchase food is easy.	4.67	Strongly Agree	3.91	Agree
Access to various foods, including fruits, vegetables, grains, and proteins are available.	4.40	Strongly Agree	3.85	Agree
Access to buy food now with payment to be made later is a not an option.	2.31	Disagree	1.75	Strongly Disagree
Access to buy food with designated money for it.	1.66	Strongly Disagree	1.44	Strongly Disagree
Average Weighted Mean	3.26	Not Sure	2.74	Not Sure
Stability				
Stability in food intake is reflected in the household eating the right amount of food.	3.32	Not Sure	3.43	Agree
Stability in food security is present as the household eats when they feel hungry.	3.26	Not Sure	3.83	Agree
Stability in food access is ensured as the household feels confident about not losing access to food due to natural disasters.	2.43	Disagree	2.18	Disagree
Stability in diet is shown as the household enjoys eating a variety of foods throughout the day.	3.93	Agree	4.17	Agree
Average Weighted Mean	3.23	Not Sure	3.40	Not Sure
Utilization				
Utilization of safe food free from contaminants, such as clean water, is practiced by the household.	4.90	Strongly Agree	4.43	Strongly Agree
Utilization of a variety of foods that meet the household's nutritional needs is common.	4.42	Strongly Agree	4.43	Strongly Agree
Utilization of proper food storage techniques ensures the household can store food without spoilage or contamination.	4.44	Strongly Agree	4.36	Strongly Agree
Utilization of proper nutrition helps the household maintain good health.	3.43	Agree	3.69	Agree
Average Weighted Mean	4.30	Strongly Agree	4.23	Strongly Agree

The results indicate that both groups generally maintain food availability and effectively utilize food resources. However, food access and stability remain significant challenges, particularly for the Blue Economy, which faces greater uncertainty due to income unpredictability tied to fishing seasonality. The Green Economy fares slightly better in food access, yet some households still struggle during lean periods caused by agricultural cycles and seasonal harvests.

Access to clean water and nutritious food supports the overall health and nutrition of both groups. However, the reliance on borrowing money to meet food needs

highlights underlying financial instability, which exacerbates vulnerabilities during times of income scarcity. While food availability and utilization are relatively stable for both groups, food access and stability are undermined by irregular income patterns. The Blue Economy's lower food access reflects the volatility of fishing livelihoods, while disparities within the Green Economy point to financial pressures linked to seasonal farming. Borrowing to purchase food further underscores limited savings and financial resources, increasing both groups' exposure to financial shocks.

These results align with studies emphasizing the role of financial capacity in food security. Food access and stability depend on consistent income and financial inclusion [16]. This division may point to vulnerabilities in food access or financial instability within the rice farming community, where certain individuals may face difficulty obtaining enough food due to irregular income, seasonal variations, or limited access to resources [10,30,40,84]. In conclusion, agriculture's dependence on seasonal cycles makes it more unstable. This resilience gives the blue economy an edge in ensuring stable food security.

Difference on the level of financial literacy, financial inclusion and food security between green economy and blue economy in San Jose, Camarines Sur

This section evaluates the difference in the level of financial literacy (knowledge, skills, attitude and behavior), financial inclusion (access, usage, quality, and welfare) and food security (availability, access, stability and utilization) between the green and blue economies in San Jose, Camarines Sur.

Table 6 illustrates a Kruskal-Wallis test, performed to assess differences in scores between the Green Economy and Blue Economy. The analysis revealed significant differences in financial literacy (behavior and attitude), financial inclusion (access, usage, quality, and welfare), and food security (availability, access, and stability). However, no significant differences were found in knowledge, skills, and utilization.

Table 6. Difference in the level of financial literacy, financial inclusion, and food security of the green economy and blue economy.

Financial Literacy	**Rank Sum**	***P*-value**	***P*-value with ties**
Knowledge			
0 = Green Economy	26,255	0.2399	0.1758
1 = Blue Economy	18,925		
Skills			
0 = Green Economy	25,986	0.1337	0.1195
1 = Blue Economy	19,164		
Attitude			
0 = Green Economy	25,695.5	0.0582	0.0099
1 = Blue Economy	19,454.5		
Behavior			
0 = Green Economy	25,192	0.0099	0.0027
1 = Blue Economy	19,958		
Financial Inclusion			

Table 6. (*Continued*).

Financial Literacy	Rank Sum	*P*-value	*P*-value with ties
Access			
0 = Green Economy	31,512.0	0.0001	0.0001
1 = Blue Economy	13,638.0		
Usage			
0 = Green Economy	29,635.5	0.0005	0.0001
1 = Blue Economy	15,514.5		
Quality			
0 = Green Economy	28,494	0.0565	0.0475
1 = Blue Economy	16,656		
Welfare			
0 = Green Economy	24,911.5	0.0031	0.002
1 = Blue Economy	20,238.5		
Food Security			
Availability			
0 = Green Economy	24,861	0.0025	0.0011
1 = Blue Economy	20,289		
Access			
0 = Green Economy	29,676	0.0004	0.0001
1 = Blue Economy	15,474		
Stability			
0 = Green Economy	29,313.5	0.0025	0.0016
1 = Blue Economy	15,836.5		
Utilization			
0 = Green Economy	28,260	0.1119	0.0967
1 = Blue Economy	16,890		

Both economies encounter similar issues in financial literacy because of limited education and exposure to financial systems [24]. Age, income, and education are some factors that affect their financial behavior. Moreover, farmers tend to have cautious attitudes and structured saving practices that are suitable to seasonal income cycles [24,75]. Due to unstable income, fisherfolk depend on informal credit and short-term strategies [48,76].

Even though they possess the basic financial understanding and skills, they still struggle to apply them in their daily life effectively. This is apparent due to the inability to supply emergency funds. As farmers tend to prioritize seasonal needs, fisherfolk's fluctuating income makes saving particularly challenging. Hence, this situates them to be vulnerable to economic shocks, indicating a need for tailored financial education and aid to enhance resilience [48,78].

The green economy illustrates better financial inclusion, shown by easy access to financial services and products such as insurance. Meanwhile, the blue economy showcased a difficulty in accessing financial services and products due to geographical isolation in coastal areas and limited utilization of financial tools. In addition, the

reason for limited utilization is that in some cases there are too many documentary requirements, the perception of unaffordable financial services, a lack of financial literacy, and a lack of trust in formal institutions.

In terms of food security, the green economy benefits from their own produce of storable grain, such as rice, providing steady food availability. In contrast, there is a struggle for the blue economy due to the perishable nature of their catches and also their unpredictable harvest. Rice farmers are nearer to markets of a town center compared to fisherfolk as they are in coastal areas; thus, farmers have more access to purchasing food. Even so, the blue economy contributes to more steady food security through their narrow reliance on seasonal cycles and resilience, compared to rice farmers that are prone to climate risk and dependence on periodic harvest. Regardless of the disparities of the green and blue economies, their food utilization has comparable outcomes, as both groups utilized the foods to be clean and safe for consumption.

4.5. Influence of financial literacy and financial inclusion on food security between the green and blue economies

This section analyzes the influence of financial literacy and financial inclusion on food security between the green and blue economies.

Table 7. Influence of financial literacy and financial inclusion on food security between green economy and blue economy.

	Food security (green economy)								**Food security (blue economy)**							
	Availability		**Access**		**Stability**		**Utilization**		**Availability**		**Access**		**Stability**		**Utilization**	
	Beta	***P*-value**	**Beta**	***P*-value**	**Beta**	***P*-value**	**Beta**	***P*-value**	**Beta**	***P*-value**	**Beta**	***P*-value**	**Beta**	***P*-value**	**Beta**	***P*-value**
Financial literacy																
Knowledge	0.1875	0.012	−0.0336	0.663	0.006	0.949	0.0936	0.138	0.0708	0.517	−0.2364	0.075	−0.0397	0.743	0.2831	0.001
Skills	−0.0308	0.688	0.03	0.709	0.0102	0.917	0.0696	0.288	−0.0264	0.791	−0.1738	0.151	0.0979	0.376	0.2505	0.001
Attitude	0.0572	0.432	0.1051	0.169	0.0042	0.964	0.0514	0.407	0.2225	0.043	0.2175	0.101	0.1187	0.326	0.1294	0.109
Behavior	0.2644	0.001	0.2607	0.001	−0.0303	0.75	0.1172	0.067	0.0324	0.795	0.1864	0.218	−0.206	0.138	0.0644	0.483
Financial inclusion																
Access	−0.0851	0.117	0.1414	0.013	0.039	0.57	0.1029	0.027	0.0711	0.456	0.2403	0.039	0.2017	0.058	0.1314	0.063
Usage	−0.1145	0.069	−0.1103	0.094	−0.0486	0.542	−0.0831	0.121	−0.2251	0.014	0.209	0.058	0.0471	0.639	−0.0837	0.211
Quality	0.0909	0.27	0.0889	0.303	−0.0887	0.398	0.1057	0.133	0.1041	0.403	−0.0628	0.677	0.0694	0.615	0.0374	0.683
Welfare	0.1316	0.217	0.166	0.138	0.2951	0.03	0.1273	0.162	−0.0137	0.924	0.2122	0.225	0.0088	0.956	0.0411	0.699

Table 7 presents the result of multivariate linear regression on the influence of

financial literacy and financial inclusion on food security. It shows that in terms of availability, the knowledge and behavior have a significant influence on food availability for the green economy, while for the blue economy, it is the attitude. However, the usage for the blue economy has a negative sign beta, indicating its inverse effect. With regards to food access, for the green economy, behavior and access have the influence, while for the blue economy, access and usage have the influence. Pertaining to food stability, for the green economy, welfare is the only variable that has the influence; meanwhile, for the blue economy, access has solely the influence. Concerning food utilization, for the green economy, access is merely having an influence. As to the blue economy, knowledge and skills have an influence on food utilization.

The Green Economy shows that financial literacy (particularly knowledge and behavior) and financial inclusion (specifically behavior and access) significantly influence food security. Farmers in the Green Economy with better financial behaviors and access to financial resources are more able to manage food availability and purchase nutritious food, which positively impacts their food security. Welfare is a key factor in improving food stability, while access to financial resources also plays a significant role in food utilization, ensuring food is well-preserved and used efficiently.

In contrast, the Blue Economy faces unique challenges. The financial literacy in terms of attitudes has an influence on food availability, whereas there is an inverse effect regarding the impact of financial usage. This is likely to a large portion of their income money being directed to the contribution on savings, insurance premiums, and payment on credit, instead of allocating it on food. Which leads to a decrease in food availability. Moreover, this is amplified by the reliance on the informal financial system, where access to tailored financial services stimulates more food security challenges.

Access to financial inclusion positively influences food access, allowing fisherfolks to buy varieties of foods. This variable plays a critical role in food stability, as it aids to alleviate vulnerabilities during environmental or economic disturbance. Moreover, financial knowledge and skills provide improvement in food utilization by enabling better management of food preservation technologies.

Based on the result, a well-established financial behavior and access to financial resources are vital for attaining food availability and utilization for the green economy. Thus, proficient behavior and access lead to betterment of food security outcomes by the farmers, especially during non-harvest periods and climatic disruption.

Regarding the blue economy, financial attitude has a significant influence on food availability, indicating that fisherfolk's short-term financial decision-making affects their ability to guarantee food availability supply. However, in terms of financial usage, it provides a negative influence on food availability, which signifies its inverse effect. This underlines the significance of enhancing access to formal financial services and proper usage and planning of financial products and services. Financial knowledge and skills provide a better food utilization outcome, which is vital for long-term food sustainability.

From previous studies highlighting the significance of financial literacy and inclusion in solving food insecurity, these findings aligned with them. Having financial access and well-established financial behaviors improves food security [24]. While

part of financial knowledge in providing better management of resources and acquisition of nutritious food is important [35]. For the Blue Economy, fisherfolk's attitudes and financial skills impact food availability and utilization, while the vulnerabilities are caused by poor financial access and usage [10,48,55].

Table 8 exhibits the multivariate linear regression result for the influence of financial literacy and financial inclusion on food security. In terms of food availability, knowledge and behavior have an effect. Additionally, usage has an impact on food availability, however inversely. Regarding food access, the attitude, behavior, and access have the significant influence. For the food stability, the welfare has only the significant influence. Moreover, with regards to food utilization, there are four variables that have a significant impact, which are knowledge, skills, behavior, and access.

Table 8. Influence of financial literacy and financial inclusion on food security.

	Food security							
	Availability		**Access**		**Stability**		**Utilization**	
	Beta	***P*-value**	**Beta**	***P*-value**	**Beta**	***P*-value**	**Beta**	***P*-value**
Financial literacy								
Knowledge	0.1555	0.0100	−0.0666	0.3260	−0.0180	0.8030	0.1552	0.0020
Skills	−0.0534	0.3490	−0.0482	0.4530	0.0209	0.7610	0.1557	0.0010
Attitude	0.0917	0.1180	0.1406	0.0340	0.0358	0.6120	0.0842	0.0810
Behavior	0.2050	0.0010	0.2328	0.0010	−0.0625	0.4070	0.1001	0.0530
Financial inclusion								
Access	−0.0411	0.3660	0.1795	0.0010	0.0653	0.2330	0.0973	0.0100
Usage	−0.1462	0.0030	−0.0143	0.7980	0.0092	0.8770	−0.0596	0.1430
Quality	0.0638	0.3340	0.0682	0.3600	−0.0733	0.3570	0.0380	0.4840
Welfare	0.1139	0.1750	0.1537	0.1050	0.2188	0.0310	0.1125	0.1030

The findings emphasize the different influence that financial literacy and financial inclusion have on food security. Financial literacy, particularly knowledge and behavior, affects attaining food availability. However, in terms of financial usage, it has a negative effect on food availability. Indicating that the more an individual uses financial services or products, the lessens the food availability, such as payment for past credits, putting on savings, or contributing to insurances. Which reduces the resources in purchasing food. Moreover, having a positive attitude, responsible financial behavior, and access to financial systems leads to proper food access, where individuals secure varieties of nutritious foods.

For food stability, only the financial welfare has a significant influence. This indicates safety nets, including insurance and savings, cater to a vital but narrow part in stabilizing food access during economic or environmental disruption.

There are four significant factors that influence food utilization, which are knowledge, skills, behavior, and access. This suggests that through decisive financial measures, practical skills, financially appropriate behavior, and access to financial services and products, we can collectively improve the capacity to store, preserve, and consume safe and clean foods, resulting in a better nutritional outcome.

Furthermore, the results highlight the significance of financial literacy and inclusion in building food security. Thus, as individuals have financial literacy, especially knowledge, skills and behavior that is essential in managing resources effectively, at the same time, financial inclusion provides access to services and products that help households to navigate economic challenges. However, through this individual should be aware of proper usage of financial products as it reduces the food availability, when not properly manage.

These findings align with the studies that focus on the interconnectedness of financial literacy, inclusion, and food security. The importance of financial knowledge must be emphasized and access to financial products and services that empower households to address the challenges in attaining food security must be promoted, for instance, availing loans for agricultural production or managing income variability to minimize the constraints and promote development [24,35,77,78,84].

5. Conclusion and recommendation

This study provides a comparative analysis of the green and blue economies, which has not been extensively explored in the context of financial literacy, inclusion, and food security. It offers empirical evidence on the role of financial literacy and inclusion in enhancing food security among vulnerable populations in a developing country context. The findings have practical implications for policymakers and stakeholders in designing targeted interventions to improve financial literacy and inclusion in both sectors.

The study was conducted to determine the difference and impact of financial literacy and financial inclusion on food security, as well as its level between the Green and Blue Economies in San Jose, Camarines Sur. Based on the study, it was discovered that both green and blue economies are financially illiterate, as they were unable to employ their positive attitudes and behavior despite having the financial knowledge and skills. Furthermore, the majority of the rice farmers and fisherfolk are situated away from the town center. Thus, they encounter difficulties in acquiring financial products and services; at the same time, they are unable to utilize them properly. Furthermore, due to their informal income status, they present transitory food insecurity.

The relatively low financial literacy levels among rice farmers and fishermen in the study area are precisely why this research is significant. By examining these groups, we aim to highlight the critical need for targeted interventions to improve financial literacy and inclusion, which can have a direct impact on food security. While we recognize the value of studying other subjects, we have chosen these groups because they are central to the green and blue economies in the region and are among the most vulnerable to food insecurity.

Utilizing the Kruskal-Wallis test, it was revealed that the two groups differ significantly in terms of financial literacy, particularly in behavior and attitude, due to differences in income patterns. Specifically, the Green Economy relies on seasonal income, while the Blue Economy depends on daily catches. Despite both groups demonstrating knowledge and skills indicative of financial literacy, they lack the corresponding attitude and behavior necessary to apply these effectively. Their

mindset aligns with that of financially literate individuals, but they fail to translate this into action, largely due to the unpredictability and variability of their incomes.

The study also found significant differences in financial inclusion between the two groups concerning access, usage, quality, and welfare. These disparities are attributed to geographical and systemic challenges, such as the coastal isolation of the Blue Economy and institutional barriers faced by both groups. The Green Economy demonstrates greater advantages compared to the Blue Economy. While both face location-related challenges, the Green Economy benefits from easier access to banks and financial tools, such as insurance. Although both groups possess insurance, it is typically bundled with loans obtained from microfinance institutions rather than being actively sought. Despite its necessity, insurance is not prioritized as a financial product by either group. Improved access to financial services facilitates the utilization of financial products, increases awareness of their quality, and enhances overall welfare.

In terms of food security, the Green and Blue Economies exhibit distinct differences. For availability and access, the Green Economy has an advantage due to their location and reliance on stored resources such as rice, leaving them to focus primarily on securing daily viands. In contrast, the Blue Economy, situated in coastal areas, depends heavily on daily fish catches, making their food supply more variable. However, in terms of stability, the Blue Economy surpasses the Green Economy due to their resilience and adaptability, as they are less reliant on seasonal cycles.

Furthermore, it is concluded that financial literacy and financial inclusion significantly influence food security. However, their effects vary depending on the specific dimensions of each variable. To wit, it was revealed that knowledge and behavior are critical in ensuring food availability. Though, in terms of usage, there is a negative influence that suggests funds intended for savings, insurance, or credit payment may reduce the immediate resources available for food. Regarding access, having positive attitudes, responsible financial behaviors, and access to financial systems caters to a better attainment of food access. For stability, welfare is the sole variable that has influence, which demonstrates that safety nets, such as insurance and savings, are critical in attaining food stability. Moreover, food utilization has four key variables that influence utilization, which are knowledge, skills, behavior, and access. Suggesting that with financial decision-making, practical skills, and access to financial services, it collectively leads to clean and safe food consumption.

Addressing the gaps in attitude and behavior, alongside improving access to financial tools and resources, is crucial for enhancing food security outcomes for both groups. Considering that the Green and Blue Economies are part of the poverty line, this results in limited financial literacy and financial inclusion, which can adversely affect their food security. Hence, policymakers should collaborate with financial institutions to establish mobile banking services and community-based financial hubs in remote coastal and rural areas. These initiatives would help mitigate geographic challenges and promote financial inclusion. Additionally, lending institutions, particularly microfinance organizations, should integrate financial literacy training into their loan processes to help beneficiaries understand the importance of insurance and other financial tools. Certain aspects of financial inclusion, particularly in terms of usage, have been found to negatively influence food security, indicating an inverse relationship. To address this, programs such as budgeting and saving workshops,

microfinance and credit education, and seminars must be implemented to improve these aspects, ultimately enhancing food security outcomes. Future researchers are encouraged to develop or adopt standardized assessment tools that comprehensively measure financial literacy. Such tools will ensure accurate evaluation of respondents' financial literacy levels, providing a more reliable basis for future studies and interventions.

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Article

Evaluating multidimensional energy poverty of South Asian countries: An in-depth analysis using household surveys

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Abstract: This study examines the multidimensional energy poverty index (MEPI), headcount ratio, and intensity in six South Asian countries. Using two datasets (India, 2005 and 2015), (Bangladesh, 2011 and 2017), (Afghanistan, 2010 and 2015), (Pakistan, 2012 and 2017), (Nepal, 2011 and 2016), and (the Maldives, 2009 and 2016), this study employs an adjusted MEPI to compare each country's effort in multidimensional energy poverty reduction (2005 to 2017). The empirical results indicate that India, Bangladesh, Pakistan, Nepal, and the Maldives significantly reduced MEPI, headcount ratio, and intensity compared to past years. However, in the case of Afghanistan, MEPI and the headcount ratio increased. The empirical results further indicate that although there has been a significant reduction in MEPI, the deprivation of modern cooking fuel and access to electricity remains high in India, Bangladesh, Pakistan, and Nepal. The study invites attention towards clean energy sources and proposes that if these countries provide modern energy fuel to households, a significant reduction is possible in the MEPI score. In our study, the results obtained with modern cooking fuel significantly dropped MEPI, headcount ratio, and intensity. These findings explain the necessary attention toward multidimensional energy poverty reduction strategies in South Asia and other developing countries.

Keywords: multidimensional energy poverty; multidimensional energy poverty reduction; multidimensional energy poverty index; South Asia; policy implications

1. Introduction

Energy poverty is among the most critical barriers to sustainable development, especially in the developing world [1]. The United Nations' Sustainable Development Goal 7 (SDG 7) focuses on ensuring that everyone has access to affordable, reliable and modern energy. However, thousands of households, particularly in South Asia, lack access to clean cooking facilities, electricity and other modern energy services. The absence of access in turn constrains socio-economic advancement and expands inequalities and environmental devastation. Energy poverty is considered a multidimensional phenomenon [2]; which includes a lack of access to modern energy fuel and, a lack of affordability to buy televisions, refrigerators, and mobile phones [3–5]. Multidimensional energy poverty is a social and economic problem worldwide, and it has a negative impact on health, the environment, and the economy. The World Economic Forum confirms that due to contaminated fuel burning such as coal, wood, straws, and animal dung, 1 of 5 deaths is caused by fossil fuel consumption [6]. The consequences of multidimensional energy poverty are not just having access to modern energy services; this multidimensional energy poverty impacts physical and mental illnesses, as most people depend on contaminated fuel consumption for cooking, which caused millions of premature deaths [7,8].

Multidimensional energy poverty represents a significant challenge in developing countries, where restricted access to affordable energy and insufficient infrastructure exacerbate the situation. It is imperative to address these issues, as alleviating energy poverty can enhance livelihoods and foster sustainable development. Electricity access is essential for households as all the appliances and physical assets like refrigerators and televisions are operated with electricity. Access to clean fuel allows societies not to spend time collecting firewood, dung, or straws for cooking purposes. Moreover, cleaner energy can provide a carbon-free environment, and prevent respiratory and other health issues in children and females [9,10]. Thus, multidimensional energy poverty reduction can improve living standards and ensure a safe and healthy life. As energy poverty is a multidimensional phenomenon that requires comprehensive and effective policies, therefore, to achieve sustainable development goals, households must have access to modern energy sources that are safe, reliable, and affordable, which can be possible through efficient government policies [11,12].

South Asia is a developing region, mainly dependent on solid fuels for cooking. The region is one of the world's most vulnerable to multidimensional energy poverty. Consequently, the population in South Asia suffers more; such as, lack of electrification, inability to produce modern appliances and poor policies are the common issues in the region. However, the region has accelerated efforts to reduce multidimensional energy poverty. According to the United Nations, approximately 870 million people in Asia had access to electricity in 2016 [13], which shows a significant achievement in energy poverty reduction. Similarly, in 2017, around 83% of the population in Bangladesh had access to electricity; among them, most of the people were living in urban areas [13]. India, and Nepal also improved electrification. India lifted 270 million people from multidimensional energy poverty in the last ten years. Pakistan was ranked among the 15 countries that successfully reduced energy poverty between 2000 and 2015 [14]. Bangladesh has achieved massive poverty reduction since 1990 when most people were living on less than $1.9; in this regard, the statistics show the country has reduced poverty from 44% to 14% until 2016 [15].

The literature on previous studies widely discusses multidimensional energy poverty in terms of affordability, reliability, and access to modern energy services; in contrast, to the best of our knowledge, none of the studies attempted to understand the multidimensional energy poverty trend in South Asia in comparing the past and current MEPI trend. Besides, the study critically analyzes multidimensional energy poverty from a policy perspective. With this attempt, this study aims to debate and analyze to what extent South Asian countries remain successful in multidimensional energy poverty reduction in the past and current stages. In this regard, the study compares each country (India, 2005 and 2015), (Bangladesh, 2011 and 2017), (Afghanistan, 2010 and 2015), (Pakistan, 2012 and 2017), (Nepal, 2011 and 2016), (Maldives, 2009 and 2016) past and current intensity, headcount ratio, and multidimensional poverty index score and examines their contribution to multidimensional energy poverty reduction. Second, as highlighted, South Asian countries mainly depend on solid fuels; this study proposes that if these countries provide clean energy fuels to households, a significant reduction is possible in the MEPI score. Third, based on the primary household's survey data, the empirical results provide detailed analysis, which is helpful in multidimensional energy poverty reduction. Accordingly, the study suggests

policies that can benefit socio-economic development in South Asia and other developing countries.

2. Literature review

2.1. Impacts of energy poverty on social development, environment, and health

Energy poverty should be understood as a form of capability deprivation [16]. They emphasize that access to modern energy services is crucial for achieving fundamental human capabilities, such as health, education, and social participation. For instance, the absence of clean cooking facilities undermines healthy living, while unreliable electricity access hampers educational and economic opportunities. This capability-based framework provides a robust foundation for understanding the multidimensional nature of energy poverty, particularly in developing countries where these deprivations are most pronounced. Energy poverty is a major cause of deprivation, affecting human well-being, the environment, and economic development [17–19]. Consequently, energy poverty, a multidimensional phenomenon, is a pressing issue among developing countries due to its broad implications [7]. Lack of access to electricity and clean energy fuel is a leading destructive [20,21], which hurdles a country's economic and social development [22]. In the backward areas of India, women and children collect wood, straw, or dung for cooking, which directly impacts social well-being [9]. Further, burning solid fuel consumption increases indoor air and outdoor pollution, affecting the climate [23,24]. Firewood, straws, and animal dung also result in global warming. Every year, 2.5 million premature deaths are caused by indoor pollution, which can be controlled with clean energy fuels [25]. Contaminated fuel burning produces hazardous pollutants, which are dangerous to health. Most rural areas rely on traditional energy fuels for cooking purposes, resulting in many respiratory and lung diseases [26]. Women and children suffer more as women spend more time on cooking and children stay at home. Consequently, energy poverty is associated with mental health, especially because poor economic conditions increase stress and anxiety [27,28]. Thus, unavailability to access electricity services and traditional use of energy fuels negatively impacts economic development, human well-being, environment, and climate [29].

2.2. Energy scenario and deprivations of multidimensional energy poverty in South Asia

South Asian countries, with more than one-third of the world's population, consume 6% of the world's energy resources. The statistical figure shows the region's significant potential to harness its resources for electricity generation. However, the installed capacity is quite below to meet the electricity demand in many Asian countries. Pakistan has installed around 17,000 megawatts (MW) of electricity from oil, coal, renewable, and other resources. The government has proposed policies to generate power from renewable resources and plans to install 20% to 30% by 2030 to reduce electricity shortages [30]; the country still faces a deficit of 4000 MW. The total power installed capacity in India is about 382700 MW; among them, 45% of electricity

is generated from coal; however, the installed capacity cannot meet the demand of households. Urpelainen found that many states in India are dissatisfied due to electricity load shedding [31]. The other countries in South Asia, such as Nepal, are rich in natural resources and have great potential to generate power from solar and wind turbines; however, the country primarily uses fossil fuels for electricity generation [32]. On the other hand, 70% of Nepal's population is deprived of modern cookstoves [33]. Despite having natural resources, Afghanistan faces severe electricity shortages. Due to political instability and the fight against war, many industries have shut down their businesses in Afghanistan. The inability to provide clean fuel further worsens human life in Afghanistan. Most of the population depends on contaminated fuel, which produces many respiratory diseases [34]. In contrast, Afghanistan has a great potential to generate electricity from solar and other renewable sources. For example, 300 sunny days in a year and the number of dams determine the country with proper management can fulfill energy demands for households in Afghanistan. The Maldives set up a sound energy system with the lowest solid fuel consumption among other South Asian countries.

South Asian countries are deprived in many dimensions of multidimensional energy poverty. 87% of households in Afghanistan don't have a refrigerator, and around 50% of the population lacks basic assets like television for entertainment and learning [35]. Similarly, around 80% of the population in Bangladesh is deprived of modern cooking fuel, and many households use animal dung and burn wood and grass for cooking [5]. Likewise, the rural population in Pakistan, India, and Nepal relies on traditional and contaminated energy fuels such as straws and firewood for cooking purposes. Moreover, the study conducted by Abbas et al. [36] found that most households in South Asia are deprived of household possessions such as washing machines and mobile phones.

2.3. Energy poverty reduction

Global warming, climate change, and the increasing adverse impact of solid fuels on humans' living conditions have shifted the focus of energy policies towards an accessible, affordable, reliable, and clean energy supply [37–39]. The shift from solid fuel consumption to clean energy fuels helps many countries reduce their dependency on contaminated fuel, which further reduces energy poverty [36,40]. Similarly, electricity access significantly reduces poverty by providing opportunities for households [41]. Other studies also support that electrification reduces energy poverty and boosts economic growth [42].

With a long-term vision to minimize the dependency on contaminated fuels, many countries have shifted their energy sources from contaminated energy fuels to clean energy fuels. For instance, Liquefied Petroleum Gas (LPG), one of the sources of clean energy, was promoted in Ghana, and the purpose was to reduce the dependency on solid fuel. The government distributed modern cookstoves and succeeded in energy poverty reduction [43]. Similarly, LPG is cheap and environmentally friendly compared to other traditional solid fuels; in this vein, the Indonesian government launched an LPG program to reduce energy poverty. The program achieved massive success, through which many households shifted energy

connection from traditional kerosene to LPG connection [44]. Other studies, for instance, Wirawan and Gultom [45] examined the capability of renewable energy to reduce energy poverty in rural areas of Indonesia. The results indicate that the renewable-based program successfully reduced poor people, enriching social development and increasing small industries. Clean energy like solar power, which converts sunlight into electricity, and wind turbines, which convert kinetic energy, makes it easier and more sustainable to fulfill energy demands. Access to clean energy reduces dependency on fossil fuels; this progress improves the quality of life and positively affects health and climate [46–48]. This implies that access to clean energy is an important determinant that contributes to a sustainable environment; also, households avail themselves of an eco-friendly environment. Thus, the purpose is to improve electrification and extend clean fuel supply to households like electricity, natural gas, and LPG.

2.4. Literature gap

Most of the studies in the scholarly literature have been carried out in African countries related to energy poverty [43,49]. In Asia, most studies related to energy poverty focus on India, Indonesia, Sri Lanka, Pakistan, and other Asian countries with single-country analysis [4,50–52].

Prior research predominantly emphasizes the phenomenon of energy poverty in the context of its affordability, reliability, and the resultant ramifications on both public health and the environment. A subset of investigations has been dedicated to probing the multifaceted implications of energy poverty on economic development. Nonetheless, this current study strives to bridge existing gaps within the extant literature. Specifically, this research delves into the multidimensional aspects of energy poverty from a policy-oriented standpoint and engages in a discourse concerning the contributions of South Asian nations in the provision of modern cooking fuels, access to electricity, and other relevant dimensions.

The study compares the previous and current MEPI of South Asian countries and analyzes the MEPI score based on the available datasets (2005 to 2017). Second, the previous literature suggests that South Asian countries depend on contaminated fuel for cooking; this study proposes that if these countries provide modern cooking fuel to households, a significant reduction is possible in MEPI reduction. Thus theoretically, this study invites attention to the sources of multidimensional energy poverty reduction and empirically highlights each country's contribution to multidimensional energy poverty reduction.

3. Methodology

The criteria to measure multidimensional energy poverty are not limited to income or a single indicator. A single indicator cannot capture all aspects of energy poverty, not suitable for the energy poverty measurement [53]. Under the one-dimensional concept of energy poverty, the poverty threshold is considered based on the income and expenditure level. It sheds light on per capita income but is not enough to understand how these people cope with poverty in their daily lives. The MEPI was proposed and explained by Nussbaumer [3]; Alkire and Foster [54], and the index was

applied with the support of the Oxford Poverty and Human Development Initiative (OPHI) and the United Nations Development Programme (UNDP) in different countries. In order to measure poverty in a multi-dimensional approach, it is necessary to combine multiple dimensions/indicators simultaneously to capture gaps in different basic needs and provide comprehensive information for poverty reduction; therefore, multidimensional energy poverty measures poverty with respect to different aspects. The multidimensional energy poverty index measures energy poverty by a composite index that determines the poor households and their intensity; it provides a valuable tool for understanding poverty in its multidimensionality, considering those who are poor and severely poor.

MEPI measures energy poverty in terms of its intensity and headcounts in the dimension "m" over the total population of households, 'n'. This model explains, $Y = y_{ij}$, an achievement matrix in populations $(m \times n)$ of individuals i in variables j. Where by $y_{ij} \geq 0$ is the grade of individual's achievement $(i = 1, \ldots\ldots, n)$ over the variables $(j = 1, \ldots\ldots, m)$. Formally MEPI is constructed by assigning a specific weight to each indicator, such that weights sum up to 1. Since each dimension of deprivation is considered an essential aspect of energy poverty, we treat each dimension on an equal basis with respect to importance. Assigning equal weights is common in many studies on multidimensional energy poverty [55].

We identify all the households deprived of achievement and count the sum of weighted deprivations suffered by a household, $\sum_j^d wj = 1$. The model uses dual cut-off parameters, such as the deprivation cut-off z and the poverty cut-off k, the intensity and the number of people living in energy poverty. This matrix represents the achievement of deprivations across individuals and variables, where zj represents the level of deprivation in variable j and $gij = wj$ represents the matrix of deprivations. Whenever the deprivation matrix g of an individual i in a variable j exceeds the deprivation cut-off value $(gij > zj)$, the individual i is deprived of the relevant dimension. If this achievement exceeds the deprivation cut-off for any variable, the variable's assigned weight (0.16) is then included in the row vector as a result of the deprivation cut-off being exceeded, otherwise counted zero, then we created a column vector (C_i) that shows an individual's score across the variables for each individual, $ci = \sum_{j=1}^{d} g_{ij}$ Shows the summations of weighted deprivation for the ith entry. We can then find the multidimensional energy-poor individuals by setting a cut-off and applying it across the column vector. We classify an individual as being energy-poor if their sum of the weighted deprivation count (C_i) reaches the cut-off $(k \geq 0.33)$, is considered the multidimensional energy-poor. Through this way, we set out the deprived households in two out of six dimensions; otherwise, below this threshold is considered not multidimensional energy poor. Lastly, a censor column vector $(C_i k)$ is used for truncating the observations for the households that are multidimensional energy-poor. After computing the necessary indices, finally, we can compute the headcount ratio (H) and intensity (A) by the following equations for the multidimensional energy poverty index.

$$H = q/n \tag{1}$$

$$A = \sum_{i-1}^{n} ci(k)/\mathrm{q} \quad (2)$$

where,

n = total population;

q = number of poor households;

$ci(k)$= deprivation count of the multidimensional energy poor.

The MEPI, which is the product of the headcount ratio and intensity, can now be calculated by the following equation.

$$\mathrm{MEPI} = H \times A \quad (3)$$

3.1. Multidimensional energy poverty dimensions and dataset

As energy poverty is a multidimensional phenomenon, this study employed an adjusted multidimensional energy poverty index to measure energy poverty. Based on the available data, six South Asian countries—India, Bangladesh, Afghanistan, Pakistan, Nepal, and Maldives—are part of this research. **Table 1**. provides detailed information on dimensions, indicators, and their weights and the deprivation cut-off explanation. For example, cooking fuel reflects the type of fuel used for cooking, such as electricity, gas, kerosene, animal's dung, LPG, etc. Under the cooking fuel dimension, if a household has modern cooking fuel, it is coded with 1, otherwise zero for the contaminated cooking fuel (animal dung, charcoal, straws, coal and others). Lighting reflects whether a household has an electricity connection (1) or not (0). Similarly, assets such as a refrigerator, television, and mobile phone are reflected as the owner's assets and coded with (1), if the household possesses these assets; otherwise, zero. The indoor pollution dimension provides the detail of whether a household has a separate kitchen (1) or not (0).

Table 1. Dimension, indicators, and threshold of deprived households.

Dimensions	Indicators and their weights	Deprivation cut-off explanation
Cooking fuel	Type of cooking fuel (16.66)	Deprived if households use fuel other than electricity, natural gas, Biogas, or LPG.
Lighting	Electricity access (16.66)	Deprived if a household has no electricity access.
Household appliances	Refrigerator (16.66)	Deprived if a household has no fridge.
Entertainment	Television (16.66)	Deprived if a household has no television.
Communication	Mobile/Phone (16.66)	Deprived if a household has no Mobile/Phone.
Indoor pollution	Separate kitchen (16.66)	Deprived if a household has no separate kitchen for cooking in the household.

The data was collected from the United States Agency for International Development. The USAID is an international development agency that conducts different surveys in Pakistan. Similarly, USAID works in India, Bangladesh, and other South Asian countries. The agency collects surveys on nutrition, childhood mortality, health, and household conditions. A dataset from 2005 to 2017 (DHS Phase V, VI and VII) was collected after formal approval from the DHS Program website. A dataset of 459,470 households from the past survey and 674,833 households from the recent survey was collected for six South Asian countries. The empirical results provide

essential policy suggestions to reduce multidimensional energy poverty in South Asian countries based on past and recent data.

4. Empirical results and discussion

This section presents the results of each country's MEPI score, headcount ratio, and intensity. **Tables 2** and **3**, and **Figure 1** summarize the results obtained from past and latest surveys of MEPI. In Afghanistan, the headcount ratio increased from 0.75 (in 2010) to 0.91 (in 2015), and the MEPI score increased from 0.40 (in 2010) to 0.43 (2015).

Table 2. Results of headcount ratio, intensity, and MEPI (based on past household survey data).

Year	Country	H	A	MEPI
2010	Afghanistan	0.75	0.53	0.4
2011	Bangladesh	0.89	0.6	0.53
2005	India	0.79	0.58	0.46
2011	Nepal	0.91	0.68	0.62
2012	Pakistan	0.79	0.54	0.43
2009	Maldives	0.25	0.34	0.08

Table 3. Results of headcount ratio, intensity and MEPI (based on recent household survey data).

Country	Year	H	A	MEPI
2015	Afghanistan	0.91	0.47	0.43
2017	Bangladesh	0.77	0.47	0.36
2015	India	0.64	0.51	0.33
2016	Nepal	0.75	0.4	0.3
2017	Pakistan	0.47	0.49	0.23
2016	Maldives	0.03	0.37	0.01

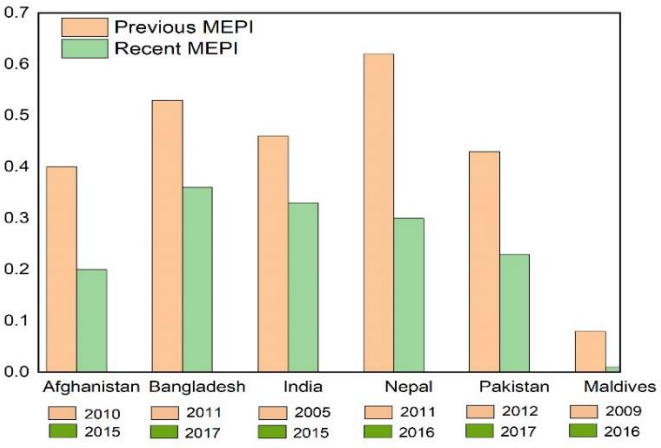

Figure 1. Comparison of past and recent MEPI.

Bangladesh significantly reduced multidimensional energy poverty. Compared to

2011, the MEPI score declined from 0.53 in 2011 to 0.36 in 2017. The headcount ratio dropped from 0.89 to 0.77, and intensity dropped from 0.60 to 0.47 between 2011 and 2017. At the same time, in Bangladesh, there has been an increase in the percentage of modern cooking fuel from 22.8% in 2007 to 33% in 2017. Besides, access to electric power supply increased from 57.1% to 63.4% (2007 to 2017), see **Figures 2** and **3**. India, the most populous country in South Asia, has succeeded in multidimensional energy poverty reduction during the period between 2005 and 2015. The results show India reduced its MEPI score from 0.46 in 2005 to 0.33 in 2015. The results further revealed a significant decline in headcount ratio from 0.79 to 0.64, and intensity declined from 0.58 to 0.51 during the years' period (2005 to 2015). Results presented in **Figure 2** further show that the deprivation of cooking fuel dropped by around 10% in India between 2005 and 2015. In contrast, access to power supply increased around 16% during these ten years in India. Nepal, compared to 2011, has reduced the MEPI score by more than 50% in 2016. The headcount ratio declined from 0.91 (in 2011) to 0.75 (in 2016), and intensity declined from 0.68 (in 2011) to 0.40 (in 2016). Moreover, access to modern energy fuel increased from 17% in 2011 to 30% in 2017; also, there has been an increase in the percentage of electricity connections from 70.6% in 2011 to 88.7% in 2017. The second most populous country in South Asia, Pakistan reduced the MEPI score from 0.43 in 2012 to 0.23 in 2017. The headcount ratio declined from 0.79 in 2012 to 0.47 in 2017. At the same time, there was an increase of 11.2% in access to modern cooking fuel (from 2011 to 2017). Lastly, we checked the results for the Maldives. The Maldives, a country with the lowest MEPI score of 0.01 in South Asia, has provided power supply and modern cooking fuel to households. More than 96% of households in the Maldives use modern cooking fuel, and 99% have electricity connections.

The results presented in **Table 3** show that Afghanistan, Bangladesh, India, and Nepal are the highest multidimensional energy-poor countries, respectively. Pakistan and Maldives are the least multidimensional energy-poor countries with MEPI scores of 0.23 and 0.01, respectively. Although these countries have declined in headcount ratio, intensity, and MEPI score, the findings of the result show that most countries in South Asia are still deprived in many dimensions. **Figures 2** and **3** compare previous and recent access to modern cooking fuel and access to electricity.

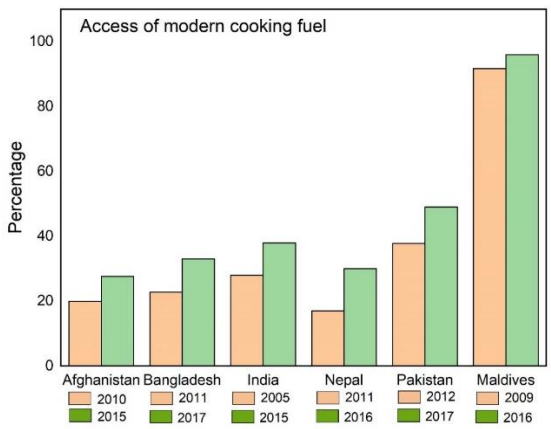

Figure 2. Access to modern cooking fuel (past and recent comparison).

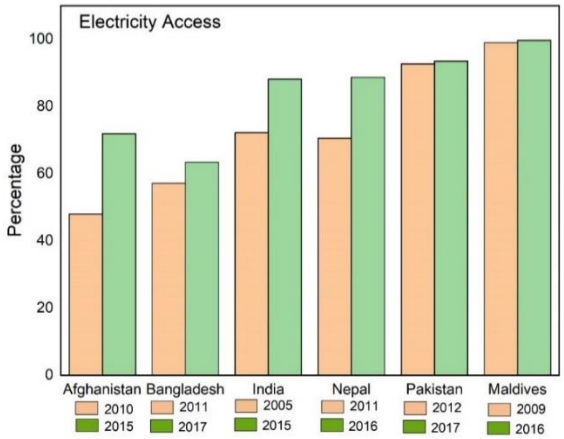

Figure 3. Electricity access (past and recent comparison).

We further separated households in rural and urban areas to assess households deprived in each dimension. The results revealed that around 96% of households in rural areas and 60% of households in urban areas of Bangladesh are deprived of modern cooking fuel; furthermore, 88% and 68.28% are deprived of refrigerators and education in rural areas, compared to 62.2% and 31.8% in urban areas of Bangladesh, respectively. Most of the rural areas in India are deprived of modern cooking fuel (76.2%), refrigerators (82.4%), entertainment (47.9%), and electricity (15.8%). Whereas, compared to households in rural areas, urban households are less deprived in India. In urban areas of India, 26.4%, 19.5%, and 14.6% are deprived of indoor pollution, modern cooking fuel, and entertainment, respectively. Around 95.2% and 88.2% of households are deprived of refrigerators and clean fuel in rural areas of Nepal. In contrast, households in the dimension of indoor pollution, electricity, and entertainment are deprived by 33.5%, 17.2%, and 16.4%, respectively. Urban households' deprivation in the dimensions of a refrigerator, modern cooking fuel, indoor pollution, and entertainment is 80.7%, 59.4%, 26.3%, and 25.5%, respectively. In rural areas of Afghanistan, the households are more deprived in the dimension of a refrigerator (95.5%), modern cooking fuel (87.4%), entertainment (62.8%), electricity (34.2%), and indoor pollution (19.5%), respectively. However, the results indicate that urban households in Afghanistan are less deprived than households in rural areas. The results show that in Afghanistan, 63.4%, 30.2%, and 22.9% of urban households are deprived of the dimensions of a refrigerator, modern cooking fuel, and entertainment. Rural households in Pakistan are also more deprived of modern cooking fuel (77.6%), refrigerators (62%), entertainment (54%), and electricity (11.7%); in contrast, 24.4%, 23.3%, and 20% of urban households are deprived in the dimension of a refrigerator, modern cooking fuel, and entertainment, respectively. The Maldives is the least multidimensional energy-poor country; less than 2% of households are deprived of modern cooking fuel and electricity in urban and rural households; however, the results indicate the Maldives is more deprived in the dimension of indoor pollution (73.1%) in urban households.

Overall, the above results explain that deprivation of modern cooking fuel, access to electricity, and refrigerators contribute more to multidimensional energy poverty in South Asian countries; the above findings also explain that rural households suffer more than households in urban areas. The results indicate that most countries depend

on contaminated fuel for cooking; however, providing them with modern fuel may significantly reduce multidimensional energy poverty. As proposed in the beginning, if these countries are provided with modern cooking fuel, we expect a significant drop in MEPI score. **Table 4**. presents the results obtained with modern cooking fuels such as electricity supply, gas, and LPG connection. Surprisingly, we found interesting results. The results show that, with modern cooking fuel, the MEPI score dropped significantly. For example, Afghanistan, Bangladesh, India, Nepal, and Pakistan can reduce MEPI scores from 0.43, 0.36, 0.33, 0.30, and 0.23 to 0.27, 0.26, 0.21, 0.13, and 0.15, respectively. Maldives has the lowest MEPI score with 0.01 and has already provided more than 97% modern cooking fuel to households. These findings confirm that cooking fuel is one of the leading causes of increased MEPI scores.

Table 4. Results of headcount ratio, intensity, and MEPI (based on past household survey data with modern cooking fuel).

Country	Year	H	A	MEPI
2015	Afghanistan	0.63	0.43	0.27
2017	Bangladesh	0.58	0.44	0.26
2015	India	0.49	0.44	0.21
2016	Nepal	0.36	0.36	0.13
2017	Pakistan	0.36	0.41	0.15
2016	Maldives	0.03	0.34	0.01

H = Headcount ratio, A = Intensity.

To eradicate energy poverty, Bangladesh initiated different programs. Bangladesh covered 10% of households by providing solar home systems, and it is one of the largest plans in the world. During the 6th plan period, Bangladesh set a skills and development policy to reduce poverty and increase employment. The country also banned fuel generated from bricks; thus, a priority was given to promoting modern cooking fuel. The Government of India offers subsidies on gas to encourage clean energy. Moreover, around 80 million LPG connections were supplied in 2019, which shows that India has spent a significant amount to reduce energy poverty [56]. Different programs and strategies have been formulated to lift the economically weaker sections out of poverty in Pakistan, such as successful businesses, successful farmers, and successful skills programs under successful youth programs to promote small businesses and decrease unemployment. The priority of the Pakistani government is to make the lower classes self-sufficient in employment; these programs provide large-scale new entrants in businesses and low-cost housing. However, the power crisis is getting worse across the country in Pakistan during the summer season. Rural areas of Pakistan are most affected by the load shedding of electricity and gas. The government of Pakistan has no proper strategy to overcome power crises and provide clean fuels to households. In Maldives, more than 98% of households have access to electricity and modern cooking fuel, and Maldives is the only country that utilizes a minimum level of solid fuels. Nepal is also one of the 22 countries that reduced multidimensional energy poverty faster than income poverty [57].

5. Conclusion and policy suggestions

The paper compares multidimensional energy poverty in South Asian countries, India (2005 and 2015), Bangladesh (2011 and 2017), Afghanistan (2010 and 2015), Pakistan (2012 and 2017), Nepal (2011 and 2016), and the Maldives (2009 and 2016). Using two datasets by employing an adjusted multidimensional energy poverty index, the study analyzes to what extent these countries remain successful in multidimensional energy poverty reduction. The results revealed that South Asian countries had declined the multidimensional energy poverty index, headcount ratio, and intensity compared to the past years. However, in the case of Afghanistan, there has been an increase in MEPI scores. Based on the current household survey data, the results revealed that Afghanistan, Bangladesh, India, and Nepal are the most multidimensional energy-poor countries, respectively. At the same time, Pakistan and Maldives are the least multidimensional energy-poor countries. Overall results show that the deprivation of modern cooking, lighting, and refrigerators is the most dominant indicator in these countries except for the Maldives. This implies that most households in these countries depend on fossil fuels for cooking and cannot afford electricity. Finally, the objective of this study was to assess the multidimensional energy poverty level if these countries provide modern cooking fuel to households. We find interesting results with modern cooking fuel. The results confirm a significant MEPI score, headcount ratio, and intensity reduction. Afghanistan, Bangladesh, India, Nepal, and Pakistan can reduce the MEPI score by 37.2%, 27.7%, 36.3%, 56.6%, and 34.7%. The Maldives is the only country that provides more than 97% of modern cooking fuel to households.

The study provides theoretical and practical implications for stakeholders, states, and policymakers. It is noteworthy that Asian countries have taken significant steps recently, focusing on issues related to multidimensional energy poverty. However, it was identified that the deprivation of modern cooking fuel and electricity supply is relatively high in these countries; especially, households in rural areas suffer more compared to households in urban areas; therefore, it is an urgent concern to overcome multidimensional energy poverty issues. For that, the following recommendations and suggestions are offered.

(1) Most households in rural areas rely on traditional sources for cooking. On the other hand, due to a lack of education, most people are unaware of the health consequences. The need is to educate people and spread awareness for the positive use of crops, straws, and animal dung instead of burning for cooking purposes; in this vein, the Government should pay attention to rural areas and increase awareness among farmers.

(2) Industries should be strengthened to turn farming into promising work, and the government should create a favorable environment for people to settle in rural areas. Besides, the government should protect the environment and involve the people at the village level to contribute and maintain the environment; furthermore, linking farmers to agri-markets will also benefit food security and rural development.

(3) As countries in South Asia are heavily dependent on importing oil and petroleum to meet the demands of commercial and households, around 6% oil consumption growth and 7% electricity demand are expected in these countries. In

contrast, solar and hydro energy potential is one of the largest sources to meet demands for electricity generation; for example, Pakistan, India, and Nepal have 40,000 MW, 84,000 MW, and 43,000 MW of hydro energy potential. A move towards renewable energy fulfills energy demands and enhances regional cooperation; this way, countries in South Asia may mutually expend energy for regional development. These countries may avail themselves of opportunities to initiate gas pipeline projects from neighboring countries. Suppose the gas pipeline established between Pakistan, India, and Iran and its route to Central Asian countries will promote clean energy, and it could be a step towards economic and financial development. Since Pakistan has abundant natural resources such as huge gas reservoirs available in Baluchistan, the country still faces severe gas load shedding in rural and mountain areas due to a lack of technical capability and inefficient government policies. Even this problem has become so serious that big cities suffer gas load shedding on summer days. If these resources are utilized properly, Pakistan can fulfill energy demands. Furthermore, the power crisis and lack of access to clean fuel in low-populated areas have been a challenge for every government because most households in these areas are far from the main electricity grid station. To provide electricity, governments should move towards renewable energy and give subsidies to households for solar panels; in this way, other countries in South Asia can adopt the same strategies to fulfill energy demands, living in remote areas. Besides, the government should ease taxes, provide incentives and subsidies to people, and initiate modern cookstoves for cooking. This way, the government can promote awareness, which can benefit their health and the overall environment.

(4) Asian countries are among the world's nations rich in agricultural resources, while a large portion of the population still resides in rural areas. In such a situation, the need for rural development is acutely felt. Modernization of agriculture, development of basic infrastructure in rural areas, provision of adequate employment to rural people, improvement in their living standards, and provision of basic necessities of life in rural areas can improve a living standard; furthermore, in rural areas, the Internet has allowed farmers to sell their products online as delivery of goods has also been facilitated, these are all factors that have sustainable results for the betterment of people living in rural areas.

The study is limited to Asian countries, particularly, India, Bangladesh, Afghanistan, Pakistan, Nepal, and the Maldives. This study employs an adjusted MEPI to compare each country's effort in multidimensional energy poverty reduction (2005 to 2017). By acknowledging these limitations, the study provides a foundation for future research to expand the geographical scope, and incorporate more diverse data sources.

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Perspective

Natural law theory resolving equity-excellence debates: Reimagining mathematical giftedness at the heart of sustainable education

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Abstract: Although South Africa committed itself to the achievement of the United Nations (UN) sustainable development goals, progress in education has been hampered by controversies about equity and excellence. Although some believe that the equity vs. excellence tension will and should never be resolved, this paper's point of departure is that learner achievement will be made less difficult when equity and excellence are prioritized correctly. The paper proposes that prioritization is possible through the natural law theory, yet few if any studies have explored that perspective in South Africa. Four research questions then shape the arguments. Following a dialectical approach, the paper shows that since Aristotle's time, the notion of natural law has been accepted as one of the most fundamental concepts of our civilization. Through the natural law theory, equity is not only viewed as the highest form of law but is also the highest form of any good or pleasure, hence excellence. This implies that in education, without actualizing learners' potential or excellence of their nature, equity has not been achieved for them. Through the theory, the paper shows South Africa's behaviors that violate natural law. However, this is not sustainable as it only provides the nation with temporary happiness instead of true happiness in accordance with nature. This according to Aristotle's natural law theory is hedonic happiness instead of eudemonic happiness. Contrary to beliefs that violators of natural law go scot-free, nature is red in tooth and claw and its punishment is evident in the vicious cycles, such as a low happiness index, high crime rates, high unemployment rates and poor service deliveries that plague South Africa. In terms of theory, the natural law theory allows for more precise definitions of equity and sustainable development which are currently lacking in all the previous debates. In terms of practice, both the natural law theory and sustainable development converge in the capability approach to education. The relation between the capability perspective and education is acknowledged in the 2002 UNESCO Report "Education for all", and its distinctive feature, the human capability approach is its assessment of policies not on the basis of their impact on incomes, but on whether or not they expand the real freedoms that people value. This approach and its conversion argument say that these internal converting capabilities are highly diverse among people, which weakens the supporting argument for a resource-based equality. The conversion argument says that the importance of primary goods or resources [external conversion factors] is derivative of the individual capability [internal conversion factors] to convert them into valued functionings. A recommendation coming from such observations is that our future depends crucially on how we educate the next generation of gifted people, especially in the mathematical sciences. The paper concludes by providing an example of how a critical mass of gifted people or excellence could create equity as knowledge cascades down in an organization or society. Singapore is an example that achieves equity through its gifted education programs. The paper recommends a similar approach if South Africa were to achieve the equitable and sustainable education it aspires for its learners.

Keywords: equity; excellence; natural law; gifted education; sustainable development

1. Background context of the study

The concept of sustainable development has been on the international agenda since the United Nations Conference on Human Environment (UNCHE) in Stockholm in 1972. In 2015 South Africa signed the United Nations Educational, Scientific & Cultural Organization (UNESCO), Sustainable Development Goals (SDGs) at the Sustainable Development Summit in New York. The 17 UNESCO SDGs have been at the forefront of global development discourse since their inception in 2012. However, various reports suggest that despite their broad scope and ambition, many countries, including South Africa are still far from achieving the goals; hence there is a need to recalibrate and reimagine the SDGs if some countries were to tackle the persistent challenges of poverty, health disparities, and climate change.

Admittedly, other researchers have reimagined these goals in various ways, but this paper takes off from where the prioritization of education left off. The author agrees that the existing SDGs are laudable for placing SDG4 on education at the intersection of all the other 17 SDGs, as it enables the cycle of poverty to be broken, inequality reduced, and individuals empowered to lead sustainable lives. However, in South Africa and other countries that prioritization falls short, particularly in its incompatibility with the "all things matter" approach to education. "All things matter" is a phrase that means everything is important or that everything is of consequence, e.g., all schools matter, all subjects matter, or all students matter. Yet prioritization suggests that "some things matter" hence the two are incompatible and [1] draws our attention to the problem arguing that the optimistic but mostly unrealistic expectations of education (of the all things matter approach) result in an exaggeration in the equalization of everything from resources, subjects, and students to teachers. The approach and its subsequent relaxation of criteria for selection are myths that form part of some philosophies of education that are just too impractical to implement in the modern world [1].

Let us try and reimagine a consistent logical argument of the prioritization principle and see where it would have taken us. For example, even though UNESCO drafted 17 SDGs, according to [2], SDG4 stands out as it will determine the ability to accomplish the other SDGs and countries that can improve their schools can look forward to substantial gains in economic welfare and can begin moving toward accomplishing all 17 SDGs. Indeed, there is general concord (including the UNESCO) about the importance of education as a key determinant of success for the individual, the corporate and national economies in the 21st century, suggesting that education has a well-recognized role as an enabler for many areas under the SDGs. This implies that 'not all SDGs matter' (at least in the same way), but if we follow the same logic, we might further ask: Do all school subjects matter or at least in the same way? Researchers such as [3] defined the output of the education sector as the effect of education on the level of knowledge, skills, and competencies of students which is also referred to as investment in human capital by OECD. Borrowing results from a number of studies, it has been shown that the returns to education are not homogenous but rather heterogeneous across the population, suggesting that different student abilities impact the economy differently [4]. Hence, although all school subjects matter, more than ever before, today the Fourth Industrial Revolution [4IR] provides

compelling policy arguments for the economic importance of multiple disciplines of Science, Technology, Engineering and Mathematics (STEM) subjects, here referred to as Mathematical Sciences. Post-democratic South African Department of Education (DoE) and the Department of Basic Education (DBE) share this same view, as they have been consistent in emphasizing that the ability of all learners to succeed in today's technically oriented work environment is dependent on their understanding of mathematical sciences and their application in practical situations [5–7]. Applying the same logic as before, we ask further but do all STEM subjects matter or at least in the same way? Although these sciences are essential, data drawn by the International Association for the Evaluation of Educational Achievement (IEA) on the Trends in International Mathematics and Science Study (TIMSS) show that there is a strong positive correlation between the Human Development Index (HDI) and mathematics achievement, suggesting that mathematics matters more in the 21st-century knowledge-based economy [8]. This is understandable given that mathematics operates at the interface of multiple disciplines of STEM subjects. But does mathematics matter for every learner or at least in the same way? Although mathematics is essential for all learners as it enables an induction into science and technology, it is more critical for those preparing for the skills needed in the 4IR. Drawing from a 25-year longitudinal study of elite STEM graduates, [9] wrote a paper entitled: *Who shines most among the brightest?* From their analyses of STEM skills and their relevance in the 21st-century knowledge-based economy they have accumulated enough evidence to show that truly extraordinary advances in STEM inventions have not been the work of typical or average individuals. Rather, mathematically talented and committed individuals (such as Bill Gates, Mark Zuckerberg, Michael Dell just to name a few) have produced such advances [9]. Terman's Genetic Studies [10] and the [11] longitudinal Studies of Mathematically Precocious Youth [SMPY] are arguably among the most comprehensive longitudinal studies in psychology to date that have tracked mathematically gifted youth for more than five decades with the aim of affirming this thought. Results from these studies have confirmed beyond any reasonable doubt that mathematically talented males and females indeed became the critical human capital needed for driving modern-day, conceptual economies. These studies are instructive in that the identification of such potential is non-negotiable in the KBE and Bill Gates applied the same logic to select Ph.D. level scientists for Microsoft Research Asia in Beijing; by administering successively more difficult IQ, mathematics, and computer science tests, he eventually selected 20 people out of an initial pool of 2000! Therefore, a comprehensive and well-implemented gifted education in mathematics could offer the possibility of cultivating a society's most promising talents into a source of exceptional human capital and creative capacity [12]. These recent considerations mean that the inclusion of gifted students' programs in order to improve their academic and well-being outcomes is increasingly regarded not as an option but as a necessity [13]. In responding to the demands of the 4IR against the perennial poor performances in mathematical sciences, South African stakeholders argued in a similar way that the "obvious solution" to the mathematics crisis was to give additional learning opportunities to exceptionally gifted children and youths from previously disadvantaged backgrounds [6]. If then we peel

the prioritization onion off starting from the UNESCO 17 SDGs down to the core, we end up with a conceptualization as shown in **Figure 1**.

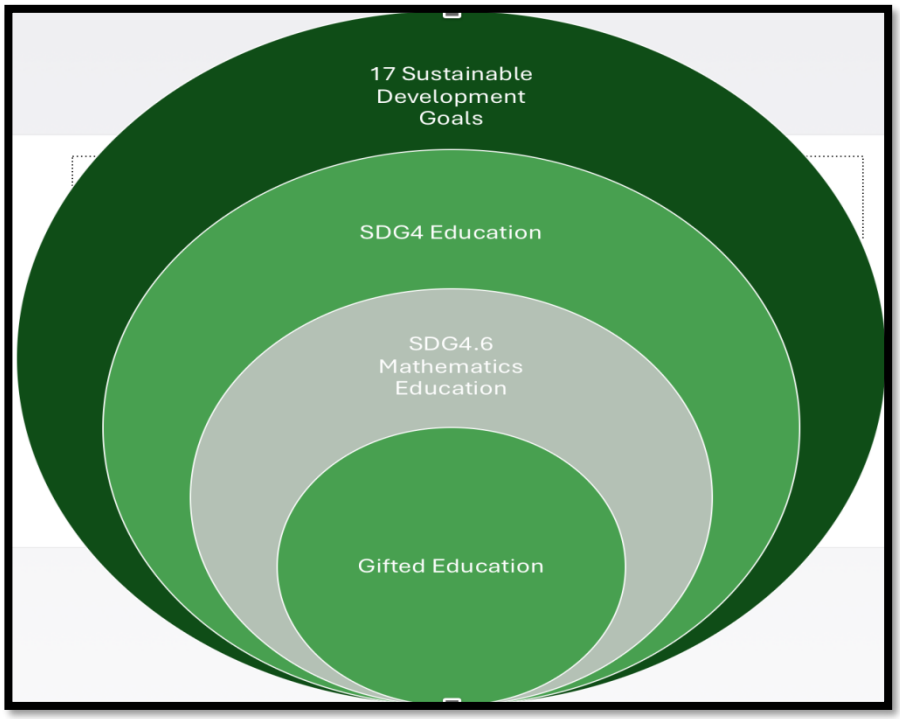

Figure 1. Conceptualizing gifted education at the heart of sustainable development.

According to [4], ignoring this economic dimension of education would not only endanger the prosperity of future generations, but it would also have extensive backlash for poverty, inequality, social exclusion, and sustainable development. Yet according to the [14] report, in many countries government and other stakeholders are still a long way from aligning their efforts with such findings, resulting in a wastage of resources and a proliferation of initiatives that are too small to have meaningful impact. So, if this conceptualization has a global appeal and seems so obvious to stakeholders in South Africa, why has it not happened and how could it be made possible?

2. Problem statement

In order to better understand the problems bedeviling South Africa in terms of achieving sustainable mathematical sciences education, it would make better sense to search for a pattern from its participation in the International Large-Scale Assessments (ILSAs). South Africa has participated in Trends in International Mathematics and Science Studies (TIMSS), Progress in International Reading Literacy Study (PIRLS) both organized by The International Association for the Evaluation of Educational Achievement (IEA), and The Program for International Student Assessment (PISA) which is run by the Organization for Economic Co-operation and Development (OECD). Professor Arthur Foshay was one of the experts present when IEA was established in 1958. Since then, Prof. Andreas Schleicher was once director for IEA but is currently the director and special adviser on education policy at the OECD who

also initiated PISA. It would be interesting to hear what the two experts (Foshay and Schleicher) say about the initial aims and objectives of these ILSAs. According to Foshay for the scholars at IEA in 1958, comparing educational systems using large-scale quantitative data was driven by an intellectual objective and clear research question summed up as: *If custom and law define what is educationally allowable within a nation, the educational systems beyond one's national boundaries suggest what is educationally possible [15]*. Similarly, according to Schleicher: *PISA does not venture into telling countries what they should do, but its strength lies in telling countries what everybody else around is doing and with what success [16]*. It should be clear from these two statements that ILSAs were designed to allow participating nations to monitor their local educational achievements as a "collaborative inquiry" which involves stakeholders generating and engaging with evidence of what was educationally possible in other successful nations which in turn would provide models for the respective participants' national improvement. Other scholars have shown how global standardization corresponds to abstract universal principles, rather than national history or circumstance [17], indicating that a world society's cultural authority precedes and sets the stage for national decision-making. However, in the past two decades, there has been a significant shift for some countries in the purpose of participating in these ILSAs from originally addressing distinct research questions to more recent participation for the sake of educational governance [18]. Hence the research-oriented rationale was replaced by a more policy-oriented rationale, one that is more linked to accountability and sadly back to international competition with no developmental benefits to participants.

In South Africa it was stated that participation in TIMSS was an opportunity to assess and benchmark the country's mathematics and science performance in an international study [19]. However, over the 25 years of South Africa's participation in ILSAs, there has been a recurrence of at least two inseparable problems, which according to [17] conceal crucial deficits that the country ignores at its peril. The first one is that of participation for accountability and competition instead of a collaborative inquiry into what other successful countries are doing as a model for national improvement. Let us look at the evidence of this problem more closely. Since 1995, South Africa has been taking part in TIMSS whose benchmarks describe the abilities fourth- and eighth-grade learners demonstrate or what learners know in mathematics and science on an achievement scale from 0–1000 points, with 500 as the center point. A score of 400 or below on the TIMSS scale indicates that a student has not achieved the minimum proficiency level for basic mathematical or science knowledge. From its initial participation, South Africa's Grade 8 learners, for example, showed a declining achievement rate as follows: 276 in 1995, 275 in 1999, 264 in 2003. Against this downward trend, critics argued that the government did not want to 'expose itself to further humiliation' [20]; hence South Africa did not participate in TIMSS 2007, but the official reason was given as: *We wanted to allow time for the many educational interventions that were being implemented, to improve mathematics and science, to take effect before testing again.* However, that reason becomes less convincing when one considers that immediately after that four-year window, stakeholders went on to field Grade 9 learners for Grade 8 tests from 2011 onwards. They also set their own local targets for mathematics as follows: for 2011 [target was 300] (achieved 352); for

2015 [target was 340] (achieved 372); for 2019 [target was 380] (achieved 389); for 2023 [target was 420] (achieved 397); for 2027 [target is 500]. In the TIMSS 2019 report, South African mathematics set targets for 2011–2019 that are described as having been achieved and students' averages have been described as having "improved" from "very low" (1995, 1999 and 2003) to "low" (2011, 2015, 2019 and 2023). Clearly setting targets below 400 was not aimed at improving learners' performance per se, and neither was the fielding of above appropriate age learners; instead, there is evidence to show that it is about accountability and competition. For example, according to [19],

> *'... the country breathed a sigh of relief when we reported that the TIMSS 2011 Grade 9 mathematics achievement scores improved by 67 TIMSS points between TIMSS 2003 and TIMSS 2011. This was the first piece of robust evidence to demonstrate that educational quality and outcomes were improving. DBE's Action Plan to 2019 called these results 'the most significant news about the system in recent years [21].*

But who are the stakeholders trying to impress by 'sigh of relief' when in fact learners have not achieved the minimum proficiency level for basic mathematical or science knowledge. While the Department of Basic Education (DBE) remains in this celebratory mode, the fact of the matter remains that (a) three-quarters of South African learners had not acquired even the minimum set of mathematical skills by Grade 9; (b) the country's targets as well as achieved averages are below the TIMSS 400; (c) the country opted for an easier version of the TIMSS tests; and (d) the years of "improvement" coincide with the years when the country fielded Grade 9 learners for Grade 8 tests. A shift from testing Grade 8 learners to testing Grade 9 learners was justified as enabling a better match between the content knowledge presented to learners in TIMSS and the curriculum coverage in South Africa [19]. In their paper, [22] draw the reader's attention to a book written by Darrell Huff entitled "How to Lie with Statistics". In that book, [23] outlines the art of 'statisticulation' which he describes as the misuse of statistics and/or errors in the interpretation of statistics, and where the secret language of statistics, … is employed to sensationalize, inflate, confuse, and oversimplify thereby creating incorrect conclusions or 'semantic nonsense.' However, all this is clear in the South African way of reporting on educational matters. In simple terms, the DNA evidence belies the validity of the claims that stakeholders are making. This is worrisome given that behind this facade of 'a system on the rise,' a recent 2023 report by the Centre for Development & Enterprise [CDE] used various indicators to conclude that almost half of all South African schools are cognitive wastelands.

A similar practice of participating for accountability and competition is also evident when National Senior Certificate (NSC) examination results are announced every January. For example, at the release of the 2021 NSC results, the DBE report of January 2022 started by outlining, as usual, the criteria for a pass at NSC level as follows: For admission to Bachelor Studies—a candidate must obtain at least 40% for the candidate's Home Language (this is compulsory); must obtain at least 50% for the candidate's four (4) other subjects, excluding Life Orientations; must obtain at least 30% for the language of learning and teaching (LOLT) of the Higher Education

Institution; must obtain at least 30% for one (1) other subjects; and must pass at least six (6) of the seven (7) subjects [24].The report went on to say:

> *... we must state that between 2008 and 2021, the Basic Education system has produced a total of more than 2.2 million Bachelor passes. These interventions have definitely improved access and retention of learners in schools; thus, simultaneously promoting equity and quality immeasurably. Therefore, this kind of consistent and improved performance, clearly illustrates our resolve to provide. ...the "equality and equity of access, as well as the equality and equity of outcomes". .... for all children, irrespective of their gender or socio-economic backgrounds. After all, even our noble Constitution, the UNESCO SDG 4, the Continental Education Strategy for Africa on the African Agenda 2063, the National Development Plan—Vision 2030, and our Action Plan 2021 enjoin us to address the six cardinal social justice principles of access, redress, equity, efficiency, inclusivity and quality of learning outcomes in our system [24].*

Clearly the reader might notice how a Bachelor pass based on very low national benchmarks is being used to justify success at national, regional, and even global levels. The national concern that these figures engendered was described long back as follows:

> *...the fact remains that the drop-out rate of 45% of all university students is nothing less than a national disaster, not necessarily because these students should obtain degrees, but because of the lamentable waste of effort. These are strong words, but unless we are shocked into action there is a very real danger that familiarity with this situation may breed acceptance [25].*

Indeed, there is evidence to show that the country was never shocked into action since then; hence, familiarity with the low pass marks has bred acceptance as the norm. Admittedly, there may be merit in adopting some locally relevant adjustments to globalized standards, but unfortunately, participation in international assessments becomes a pointless exercise if, in the end, efforts are not made to improve the performance of learners. South Africa and other countries might want to heed the OECD advice from Schleicher's perspective:

> *The world today is indifferent to tradition and past reputations, unforgiving of frailty and ignorant of custom or practice. Success will go to those individuals, institutions, and countries that are swift to adapt, slow to complain, and open to change. The task for governments will be to ensure that their citizens, institutions, and education systems rise to this challenge and international comparisons can provide useful instruments to this end [16].*

Hence, instead of making global research locally meaningful for South Africa as suggested by [19], a counter proposal by [17] is that countries have to think locally but act globally. Stakeholders need to base and readjust their strategies on how globalization will proceed given that it is ignorant of custom or practice and neither is it forgiving of frailty. Globalization will continue to move forward and like the 4IR, it provides lighthouses through this time of volatility and is irreversible because it is a revolution.

Now that participation for accountability on the ILSAs has provided us with a snapshot of the South African mathematics crisis, the general trend across other policy decisions shows that all its educational problems have their roots in the country's

prioritization of equity over excellence. Barely a decade into democracy, the Centre for Development & Enterprise (CDE) report had already identified and challenged the egalitarian practice where many education systems emerging from a history of discrimination proceed on the assumption that equity for all should come before excellence for some [26]. More recently, there is still a global view that progress, especially in mathematical sciences education elsewhere and in South Africa has been hampered by public perceptions of equity and excellence that are shaped by the local political and historical events within that country [27]. Against this background, it is reasonable for research to try to reconceptualize the foundational problem of equity vs. excellence in education. That reconceptualization might begin by repeating this question posed by [28]: *Are there alternate ways to conceptualize the problem that globalized standards seek to solve?* This is important given that research shows that plausible-sounding reform rhetoric rarely translates into large-scale improvement at the chalkface level; hence, when faced with some new interventions, researchers must exercise judgment to assess their efficacy [29]. This paper was premised on the need to look beneath the plausible-sounding surface to see whether the claims made for access, redress, equity and efficiency make sense, to ask whether there is a real danger that the new emphasis may become the latest in a series of bandwagons whose negative effects will eventually outweigh any possible benefits in South Africa.

2.1. Gap in knowledge

In South Africa, those in favor of equity before excellence have always had policy decisions in their favor because their cases are always bolstered by the country's apartheid history and persistent reality of racism and widening economic inequalities. Elsewhere it has also been acknowledged that the dual and desirable educational goals of student equity and excellence have often been in a serious struggle for scarce resources, but this struggle has often been won by equity because the problems of equity have greater immediacy than does the long-term enhancement of excellence [30]. A recurring problem with attempting to combine the two opposing beliefs is that the conflict becomes exacerbated rather than being resolved. Admittedly, this question has been the subject of exhaustive scholarly discussions; hence any attempt to add to the existing theories on these matters may seem like a venture with little prospect of producing something novel that also is useful. However, it is always healthy to question and reassess standard positions; hence it may not be too late to make a contribution, no matter how modest, to these core questions. Although [31] believed that the equity vs. excellence tension will never, and should never, be resolved, this paper's point of departure is towards the alternative view that the 'relative' or subjective nature of the quality construct as described by [32] should not allow us to abrogate responsibility for its attainment. In terms of the gap that this paper fills, we argue that in the equity-excellence debates the cardiologists are missing the heart of the matter. Indeed, equity and excellence are inseparable because the absence of one hinders full attainment of the other; however, Aristotle (384–322 BC) advised us long back that in investigating the cause of each thing, it is always necessary to seek what is most precise. Following from this advice, this paper shares the view that learner achievement will be made less difficult when equity and excellence are prioritized

correctly [33]. So the heart of the matter is the precise order of prioritization of equity and excellence and this in turn points to two important and related imperatives as follows: (a) The need to find a theory that explains why desired change has remained a deferred dream; (b) the need for the same theory to suggest what could be done to make this dream come true.

2.2. Objectives of the paper

This theory paper aims at exploring the natural law theory and its efficacy in addressing the problem of the correct order prioritization of the dual and desirable educational goals of student equity and excellence. It is premised on the view that the natural law theory would allow us to see the weakness of the join (equity vs. excellence), to pry the arguments apart, identify their constituent claims and dispose of them seriatim. To give the paper structure, the authors raise the following research questions:

1) Does natural law exist and how is its existence conceptualized and justified?
2) How could the natural law theory address the prioritization of equity and excellence?
3) How does the theory explain the mathematics crisis in South Africa?
4) What are its implications for gifted education in South Africa?

2.3. Natural law theory—A proposal

The notion of natural law has been used by both the conservative and the revolutionary-reform elements of society to either rationalize and justify existing institutional practices or to initiate radical changes and its application has been observed in modern scholarship [34–40]. Historically, natural law theories date back to ancient times during which Socrates, Plato, and Aristotle [to name a few] distinguished natural justice from legal justice. Although Shiner pointed to limitations due to imperfect translation from Greek, Aristotle's views have shaped the natural law theory in a manner that has remained relevant to date [34]. Hence, many consider Aristotle to be the father of natural law theory given that after him, the notion of natural law as a philosophical, juridical, and ethical idea was accepted as one of the most fundamental concepts of our civilization [41]. Since then, natural law has gone by various other names, such as Divine Law, Eternal Law, Moral Law, Universal Law, Law of Reason, Common Law, Higher Law or Law of Nature and this is understandable given that natural law theories have also been applied in different academic specialties.

This paper followed on [42] proposal that the controversies about excellence and equity in education are resolvable through the natural law theory. The author [43] draws our attention to how Aristotle (384–322 BC) used the terms 'equity' and 'excellence' in most of his writings (which are generally referred to as Corpus Aristotelicum) and how those teachings (a) have had a lasting impact on Western philosophy; (b) continue to shape how philosophy is perceived even today; (c) have remained a standard part of the philosophical vernacular; and (d) will continue to be studied with keen, non-antiquarian interest. According to [44] Aristotle's Greek translations of "equity" and "equitable" are *epieikeia* and *epiekis*, respectively and

Aristotle uses the terms in two senses referring both to the specific equity in legal justice and to the more general equity of the equitable man. In the specific sense, Aristotle pithily characterizes *epieikeia* as [*epanorthoma nomou, hei elleipei dia to katholou*], a correction of law, where law falls short because of its universality. This universality is accepted because the nature of legal justice is such that legislators pass laws that are universal in form, but particular cases that may or may not fit neatly within a universally phrased law are inevitable and the judge has to deal with such particular cases in an equitable manner. For example, the law might say that a driver who kills a pedestrian at a zebra/pedestrian crossing shall be charged with vehicular manslaughter. Assuming at the time of phrasing this law, there were no self-driving vehicles, what would then happen if a self-driving vehicle (which has no driver) kills a pedestrian at a zebra crossing? The mistake, Aristotle says, is really in neither the law nor the legislator, but "in the nature of the business, [*euthus gar toiauti hi tonprakton huh estin*], for from the very start such is the matter of practical affairs. In particular, when Aristotle remarks that the equitably just is something that the legislator [*ei hidei enomothetisen*], would have legislated if he had known, he seems to imply that further legislation would fill a gap existing in the current human law but before that happens equity is the Aristotelian virtue that represents the exercise of making such tailor-made, particularized judgments. Written law inevitably falls short of the standard of applicability that it wears on its linguistic face; hence it speaks universally and absolutely, but it has no right to do so. Equity corrects that deficiency [44]. Hence according to [40] not only do judges have the authority and capacity to engage in natural-law reasoning, but they must do so because they are committed to both judicial restraint and natural-law reasoning simultaneously. Judges in a free society governed by the common law derive their authority from the people and are bound by the judgments of the people and precedent when making their judgments. They are also bound, however, by a law that supersedes the judgments of the people, the natural law; hence the entire enterprise of "law" in a free society is viewed as an experiment in applying the natural law [40]. From this perspective, human law must rest its authority, ultimately, upon the authority of the natural law. The Rhetoric describes the equitable as [*to para to gegrammenon nomon dikaion*]," that justice which lies beyond the written law." In this sense both equity (*epieikeia*) and equitable (*epiekis*) are necessary virtues to address the impossibility for legal justice to fully represent 'absolute justice' [45]. This idea of absolute justice brings to mind Aristotle's standard contrast between "natural" and "positive or human" law. In the Rhetoric, he distinguishes [*nomos idios*], "particular law," and [*nomos koinos*], "universal law." While the former is divided into [*nomos agraphos*], "unwritten law," and [*nomos gegrammenos*], "written law," the latter is [*law kata phusin*], "law in accord with nature".

Besides its role of filling the gaps where positive law falls short, its second role is in correcting human law. For example, Aristotle's discussion of absolute kingship (*pambasileia*) provides a window into why the best practical regime can never be the best regime, even though it draws its power from positive law because people by nature have desires and the heart twists the rule of even the best men. Aristotle goes further to say the regime determines the nature of the citizens, the rulers and the ruled, the concept of justice they accept, and the laws they follow. Hence even the human

law designed 'positively' reflects the biases of its makers and if the king is abusive, bad, ignorant, or wicked, he and his actions have disastrous effects on the people governed by him. In a famous passage in his Ethics, Aristotle's conclusion is that equity's role is to prevent the law from adhering too rigidly to its own rules and principles when those rules and principles produce injustice. Aristotle was the first to articulate what has come to be known as the ideal of the rule of law. He shared the common Greek view that natural law was an instrument by which to constrain the exercise of political power, particularly that of tyrants, whose policies represented only their own interests and not the good of the community. Similarly, [40] warns of the tyranny arising from judicial usurpation of legislative or executive powers, calling judicial decisions based on "considerations of policy" the "terrible instruments of arbitrary power" that "cut with the keenest edge, and inflict the deepest and most deadly wounds. From this view, nature is conceived of not only as a legislator, but the supreme legislator.

For example, Hitler and the Nazis identified Germans as members of the "Aryan" race who were at the top of the racial hierarchy, hence referred to as the "master race" while Jews were referred to as the "inferior race" that was dangerous to, and must be destroyed to keep the purity of, the master race. In 1933, persecution of the Jews became active Nazi policy, but Hitler needed some laws to grant judicial legitimacy to their persecution. On the 23 March 1933, Hitler proposed the Enabling Law to the Reichstag [Parliament] also known as the 'Law to Remedy the Distress of the People and the Reich' (German Empire), a new law that was passed and signed into law the following day. Although undemocratic strategies, including propaganda and force were employed, the Enabling Act of 1933 still gave Adolf Hitler and his government power to make laws without the consent of the German parliament. As per plan, under Hitler's leadership and its racist ideology, the Nazi regime was responsible for the genocide of an estimated six million Jews and millions of other victims, whom he and his followers deemed (*Untermenschen*) sub-humans or socially undesirable. Despite this unethical behavior, the positivist ideology with its thesis that "law is law" made German jurists and lawyers defenseless against laws of arbitrary or criminal content designed by Adolf Hitler which were mocked as an "Adolphe Légalité" or Adolf's legality. Here is an example of how legal institutions can be made the object of the non-legal power struggle given that Hitler obtained and increased his dictatorial power, not in violation of law, but in accordance with and assisted by German law.

The writer [46] authored his book 'The Natural Law' in response to this Germany's political and legal crisis after he had watched with alarm as the Nazi party deftly used German legislative, administrative, and judicial institutions to impose totalitarian rule. He then remarked "Our modern dictators, are masters of legality" suggesting that dictators can take negative advantage of civil/human law to perpetuate evil. However, as Rommen put it in his book on the state, "When one of the relativist theories (such as racism) is made the basis of a totalitarian state, man is stirred to free himself from the pessimistic resignation that characterizes these relativist theories and to return to his principles. In fact, tracing the very origins of any positive or human law shows that human laws can be derived from natural law through deductive logic, similar to how scientific conclusions are derived from the principles or nature of things. A natural law doctrine is founded on the existence of principles governing the

life of society, such principles being founded on the nature of things, and in particular on the nature of man, working by the application of reason, and having to translate and develop itself into the forms of positive law as a function of changing social needs [47]. Hence from these 'principles' the system of ethics and of natural law was deduced in a rationalistic manner prompting Rommen to muse that every generation, finds a new reason for the study of natural law and for him and many others of his generation, totalitarianism provided that occasion. Similarly, in 1966 a resolution directed at United States military involvement in Vietnam stated that: "These methods of warfare offend human nature." The basic impulse that motivates such decisions presumes the existence of a morally relevant common humanity. In fact, the roots of current positive law and legal policies are rarely, if ever, totally derived from legal research and the resulting facts or evidence. The issue is not how we can or cannot keep values and underlying assumptions, such as notions of natural law, from influencing our work, but how we can systematically take them, and their influence, into consideration. Hence Locke as cited in [48] opines that without the natural law, then any system of government would be permissible, and it would be wholly immaterial that the government did not recognize the human rights that are regarded as beyond the interference of any power. This implies that there would be no sense in which anyone could be considered virtuous or vicious.

A full elaboration of the concept of natural law as a law of reason, capturing all the essential characteristics that were later developed in the legal tradition, can be found specifically in Cicero's text [49] [54–51 BC] where natural law is characterized as follows:

a) It is in accordance with reason (or it is even directly identified with reason);
b) It is in accordance with nature (it is the law of nature);
c) It is a morally relevant law (it is related to the distinction between virtue and sin), so that;
d) To act against it is morally wrong;
e) It is subject neither to human legislation, nor to the will of individuals, nor to decision by voting.
f) It is comprehensible to common sense (it does not need interpretation by a legal specialist);
g) It is applicable regardless of the local customs of individual cultures (it applies everywhere);
h) It has been and will be valid for all time (it is eternal);
i) It is immutable.
j) Its violation in itself involves punishment (violation is beyond the pale of human nature);
k) Its originator is God (as cited in [50]).

Although other theorists do not share the connection to God as the originator, the pervasiveness of natural law theory is still reflected beyond legal justice as its application spills over into the social sciences including education. This is clear in that Aristotle's politics can be understood as partly an attempt to make sense of the political as a distinct field of intellectual inquiry. In his writings in the *Nicomachean Ethics* Aristotle articulated the first principle of ethical human action where he used the word (*epieikeis)* for "good", contrasted with (*phaulos)* for "bad and argued that good is to

be done and pursued, while evil is to be avoided. Similarly, in Aristotle's ethical treatises, the term (*kakon)* bad/evil is used in a broad sense as it generally applies to things that destroy or hinder happiness (*eudaimonia)*, tarnish the joy of the blessed (*makarioi)*, or contribute to making someone miserable (*athlios)*. Evils are often referred to as "objects of avoidance" (*ta pheukta)*, which Aristotle classifies into the shameful (*to aischron)*, the harmful (*to blaberon)*, and the painful (*to lupêron*), and which have different kinds of impact on our well-being. Put simply, good, and evil reduce to what is pleasurable and what is painful, respectively [48]. However, Aristotle further defines happiness as something deeper than temporary excitement, distraction, or pleasure and this is summed up by his famous aphorism: "One swallow does not make a summer." In Aristotle's writings, the debate about *eudaimonic* vs. *hedonic* well-being usually contrasts (a) self-fulfillment with maximizing pleasure; (b) value- and virtue-oriented living with prioritizing enjoyable experiences; and (c) designing for long-term flourishing vs. seeking short-term gratification. According to [51], *hedonic* happiness is about maximizing pleasure and minimizing displeasure and he considered *eudemonia* as humanity's highest good. Similarly, while Locke equates pleasure or happiness with good, he is careful and suggests an important hierarchical distinction between (a) the good/happiness, understood as all objects that are connected to pleasure and (b) the *moral good/true happiness,* understood as objects connected to pleasure which are also in conformity with an eternal law.

Although [52] gives many examples to support this hierarchy, the specific case about alcohol-taking is sufficient for this paper. Locke notes that people take alcohol to obtain the pleasure of intoxication but drinking violates a natural law regarding the normal functioning of a healthy body and this leads to pain in the form of headache, nausea, or several other longer-term effects. In this case, drinking to obtain the pleasure of intoxication is to pursue an immediate good/happiness, which Aristotle would call *hedonic* happiness or temporary excitement, while avoiding drinking to obtain the pleasure of health is to pursue a remote-good/moral-good/true-happiness which Aristotle would call *eudemonic* happiness or the highest good. Locke further explains why people pursue short-term good/happiness rather than long-term moral good/true happiness. In his view, if every sip of alcohol were accompanied by headache and nausea, no one would ever drink, but Locke claims that the weak condition of our minds makes it easy for us to think that there could be no greater good than the relief of being unburdened of a present pain. However, in Locke's view, if we contemplate a thing long enough and clearly see the measure of its true worth, we can change our desire and uneasiness for it in proportion to that worth. Locke then concluded that there is an ordered way to choose which things to pursue as follows: (a) An ill-ordered way in accordance with our own palates or pleasures (*the good or happiness*) or (b) a virtuous way in accordance with the eternal law and nature of things (*the morally good or true happiness*).

Once the existence of an eternal law is accepted, the next question to be considered would be: *What kind of authority if any, does the natural law have to obligate?* This question is important following critics who argue that theories of natural law have come to be defined as mere speculation, of limited interest or utility in the analytical world [48]. Yet researchers have also demonstrated once again that natural law is not a mere abstraction without practical consequences but that it can and

does have a profound influence on the life and property of every living person [40]. Locke begins his treatment of this question by stating that no one can oblige us to do anything unless the one who obliges has some superior right and power over us. The obligation that is generated between such a superior power and those who are subject to it results in two kinds of duties: (1) The duty to pay obedience to the command of the superior power and (2) the duty to suffer punishment as a result of the failure to honor the first duty of obedience. In this regard there is a profound parallel between natural law and written law, as both sets of laws define rules of behavior that are designed to be in the best interest of the individual and society. Hence in an analogous way that civil or human law has the status of commanding or prohibiting certain human behaviors, Locke argued that moral good and moral evil are no more than the conformity or disagreement between our actions and the eternal/natural law. To this he immediately adds that such conformity or disagreement is followed by rewards or punishments because it would be in vain for the intelligent being who decrees the rule of law to so decree without entailing reward for the obedient or punishment for the unfaithful. Although unfaithfulness in both human or written and natural laws results in negative consequences of acting outside their boundaries of prescribed behavior, Locke warns us that the eternal law has "a just and inevitable command over us and at its pleasure can raise us up or throw us down and make us by the same commanding power happy or miserable" [48].The word 'inevitable' points to one critical difference between human and natural law, i.e., one can sometimes escape the consequences of violating human law if one does not get caught or escapes punishment yet in contrast, one is always in the grip of natural law and its consequences. The word miserable confirms a prevailing impression that nature is full of violence and cruelty: "red in tooth and claw" [37,38]. The author [37] points to the notion of natural punishment where countless examples of the vicious cycles they create such as poverty, crime and drug abuse have been given by its proponents. A vicious cycle connotes a sequence of reciprocal cause and effect in which two or more elements intensify and aggravate each other, leading inexorably to a worsening of the situation. Violation of natural law leads into such vicious cycles as one form of violation breeds other forms of natural law violations. Hence, according to [53], whoever is in violation of natural law is fleeing from himself and denying his human nature, and by reason of this very fact, he will suffer the worst penalties, even if he escapes what is commonly considered as punishment under human law.

2.4. Methodological approach—Dialectical argumentation

The second research question is about how natural law can help in the prioritization of the concepts of equity and excellence. In answering that question, this paper is making a judgment on a subject matter (equity vs. excellence), a subject matter that has been shown to apply in both legal and non-legal situations. This nature of the subject matter demands a methodological approach that allows the reader to see a common thread that connects the natural law as it applies across legal and non-legal situations. The researcher [40] consulted James Wilson's views on natural law, arguing that as a prominent jurist during the American founding, a signer of the Declaration of Independence and the Constitution, a delegate to Pennsylvania's ratifying convention,

and the jurist chosen to deliver the nation's inaugural series of law lectures at the College of Philadelphia, Wilson's views on the judge's role as it pertains to natural-law reasoning are informative today. Wilson conceived of judges and of making judgment as a common subject of man using faculties that all men have, i.e., determining the principles of right and justice through the moral sense and reason. Simply put every man legally trained or not is capable of administering justice "judicially." This judicial authority," he states, "consists in applying, according to the principles of right and justice, but the type of reasoning applicable in a judgment will vary depending on who is doing the judging (a judge or a private individual) and whether the context is the judicial administration of justice (which requires legal reasoning) or a nonlegal setting (which requires ordinary, probabilistic, and discursive moral reasoning) which involves the faculties of the moral sense and reason [40]. Bringing together Wilson's insights, [40] then conceptualized a taxonomy (**Figure 2**) for understanding the division of the types of reasoning involved in judgement in its broadest sense.

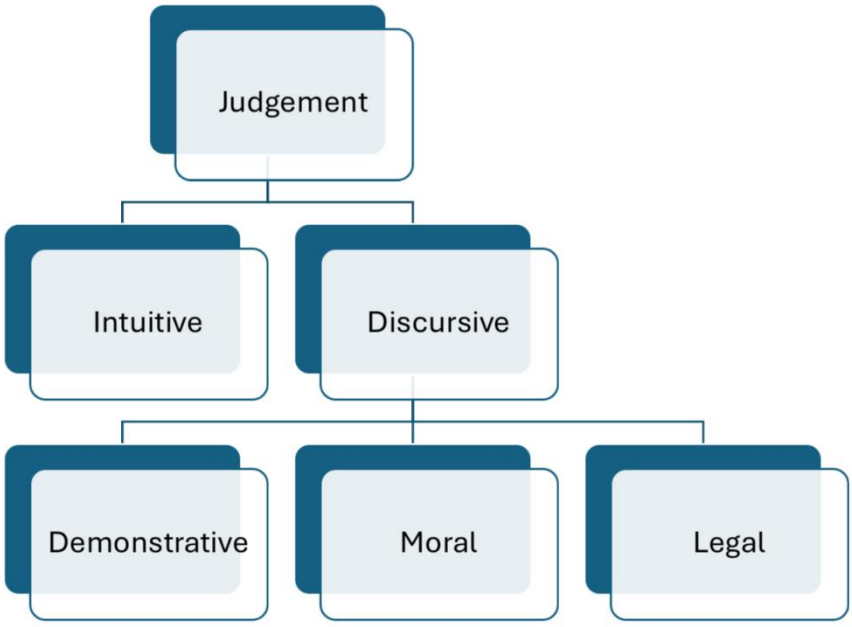

Figure 2. Terman's taxonomy for making judgment [40].

As seen in **Figure 2**, according to [40], judgments are either intuitive or discursive and both require self-evident truths (without which all reasoning is impossible). On one hand, intuitive judgments are based on the moral sense perceiving self-evident truths directly while discursive judgments are based on either demonstrative (certain) reasoning, moral (probable) reasoning, or legal (precedential/analogical) reasoning.

The distinction between demonstrative and moral reasoning was evident in Aristotle's (384–322 BC) premise and conceptualization of knowledge. Aristotle's (384–322 BC) distinction of knowledge starts with the analogy of a "white horse" which is a combination of the words "white" and "horse." Aristotle (384–322 BC) believed that white (or equity or excellence) does not exist independently like a horse but is a property of a substance. A necessary truth (like horse) is a truth that must be

true because a horse is a horse regardless of its color while a contingent truth (such as equity) is true as it happens but did not have to be true. From there, Aristotle believed that the study of a contingent truth belongs to a distinct field from scientific knowledge, and that the two (absolute truth and contingent truth) differ in their methodology and subject matter. Hence Aristotle long argued that it was necessary to distinguish between ways of being and indeed what stands out in his writings is the contrast between *episteme* and *doxa*. In Aristotle's philosophy, *episteme* is a virtue of thought that involves understanding necessary truths, while on the other hand, the Greek term *doxa* refers to the domain of opinion, belief, or probable knowledge and is defined as "public opinion, majority prejudice, middle-class consensus, that could easily be confounded with scientific knowledge, *episteme*, which is the domain of certainty or true knowledge.

There is a methodical approach to *episteme* which deals with less subjective views and uses objective observations to make arguments more substantial; that sharply differs from the way conclusions are reached using *doxa*. In this regard, Aristotle points to (a) the demonstration method or the empirical inquiry which is a method that starts with perception and uses induction and generalization to remove ignorance; and (b) the dialectic which is a method of dialogue that uses logic to validate arguments and advance knowledge [54]. Dialectic, also known as the dialectical method, is for Aristotle a lesser way of proceeding than is demonstration, the method of science; for demonstration proceeds from premises which are accepted as true in themselves (that is to say that they are essentially and thus in some sense necessarily true) and moves from them to conclusions which follow necessarily from those premises; and the middle term of such a demonstrative syllogism then provides the 'reason why' for the truth of the conclusion. On the other hand, dialectic proceeds logically from premises which are accepted on a lesser basis 'by everyone or by the majority or by the wise, or by the most notable and reputable of them', and proceeds deductively from them to further conclusions. That way of putting the matter does not, strictly speaking, assert that dialectic is inferior to demonstration, but it differs from demonstration in that it is not concerned with the pursuit of absolute truth or first principles. Aristotle makes clear in several places in *Nicomachean Ethics* that the subject matter of such dialectic investigations is opinions about right, just, good, fine, or useful, and not necessary truths or first principles. Hence, dialectic deals with matters that we deliberate about (*bouleuometha*) but for which we do not have an "art" or "craft" (*technē*), or for which we have no systematic rules." What is involved is at best what has been called 'inference to the best explanation' and what is produced is indeed 'clearer and more knowable by us' but not necessarily the absolute truth. This is so because Aristotle coined the term dialectics as a logic of the opinion, of the probable which permits reasoning in a field that, in a certain sense, is intermediate between that which is certainly true (*apodictic reasoning*) and that which is certainly false (*sophistic reasoning*). In Aristotle's view, dialectical reasoning consists in going through the difficulties on either side of opposite opinions (*pros amphotera diaporesai*); hence it can be described as the art of disputing, and of disputing in such a way as to hold one's own, whether one is in the right or the wrong—*per fas et nefas*. Therefore, dialectic is useful for the philosophical disciplines in that one is able to

address the difficulties of both sides of an argument or problem making it easier to discern what is acceptable and unacceptable in the issue under discussion.

From there, Aristotle stresses that rhetoric is closely related to dialectic. He offers several formulations to describe the affinity between these two disciplines: in the first line of the book Rhetoric where rhetoric is said to be a 'counterpart' (*antistrophos*) to dialectic; in the second chapter of the first book, it is also called an 'outgrowth' or 'offshoot' (*paraphues ti*) of dialectic and the study of character; finally, Aristotle says that rhetoric is part of dialectic and resembles it [55]. In short, Aristotle defined rhetoric as a capacity to discern what, in a particular case, will be persuasive, or more literally what the particular case will "accept" or "welcome" (*endekhomenon*), or what is "appropriate" to it. Rhetoric is linked to the ethical and political domains in the sense that any persuasive discourse must draw its premises from the common opinions that the audience accepts while at the same time it is a combination of the sciences of logic and ethics [56]. Persuasion comes about either through the character (*êthos*) of the speaker, the emotional state (*pathos*) of the hearer, or the argument (*logos*) itself [55].

This paper is premised on the view that in South Africa, persuasion has come about through both the character (*êthos*) of the speaker and the emotional state (*pathos*) of the hearer. An example of this approach can be taken from the book "Animal Farm" where Squealer used the threat of Mr. Jones' return to convince the animals to agree to the following: *The pigs receive all the milk and apples because they need more brain food than the others.* Similarly, in South Africa, many eloquent proponents justify their proposals by the threat of either apartheid coming back or on the pretext of its removal. Unfortunately, despite the emotional appeal of such proposals born out of *êthos* of the speaker *or pathos* of the hearer, [57] argues that our immersion (in ideology) is so "natural" that it renders us blind to the toxicity of what we consume in the social spaces we occupy. This paper runs away from such toxicity and aims to persuade differently through the argument (*logos*) itself of the equity-excellence nexus. In doing so, this theory paper employs both dialectic and rhetoric as a methodological approach to discern what could be persuasive in the debates for and against equity and excellence in education. This is important given that *doxa* characterizes the *doxastic* state of mind as a state of deception and the objects a person in this state is acquainted with as being deceptive or 'untrue'. Aristotle's views point to the naturalistic fallacy which is a logical fallacy that occurs when people draw conclusions about the nature of reality from observations of nature, without considering whether those observations are accurate. This according to Aristotle suggests that a different explanatory factor must be found so that what was irrelevant in the original explanation is abandoned and replaced with what is ultimately appropriate [35].

2.5. Prioritising equity and excellence through the natural law theory

There is a pervasive interpretation of the principle of equity as equal distribution of resources which is based on the rule that everyone receives the same share of resources, without regard to effort, contribution, ability, or outcomes [58,59]. While such an interpretation perpetuates the dual dichotomy within the equity-excellence nexus, [60] as cited in [33] proposed a concept of goodness that allows for the cohabitation of excellence and equality. This is so because a pursuit of equity or

equality, as a critical dimension of the human endeavor, becomes part of the pursuit of goodness and the avoidance of evil. From this view, the natural law theory does not only allow for the cohabitation of excellence and equity, but it goes a step higher to allow for the prioritization of the concepts. The terms in Aristotle's Greek standardly translated "equity" and "equitable" are *epieikeia* and *epiekis*, respectively but by far the most common meaning in his writings is the general one of *epieikeia* which simply means "excellence" or "goodness" which in the natural law theory is understood as objects connected to pleasure that are also in conformity with an eternal law. According to Aristotle, a human being's highest goal is the realization and completion of their nature and potential, an achieved excellence of doing, feeling, and thinking. Aristotle's highest good is *eudaimonia*, which he defined as the activity of the soul in accordance with virtue or excellence. He also identified *eudaimonia* with the Greek word for happiness. Aristotle goes further to argue that the highest good (excellence) and highest being in first philosophy is the prime mover; that is, the source (*archē*) of coming-to-be and excellence was a requirement for happiness and a key part of living a good life. Hence according to [61], in the domain of education, the way to achieve equity is to ensure that all children, from every racial and ethnic group, get what they need to live up to their full potential. In that sense, and drawing on the natural-law theory, researchers argue that excellence becomes an antidote for equity because without actualizing a person's potential or excellence of their nature, equity has not been achieved for that person. Hence, in today's world, society should aspire for every child to grow up to achieve his or her full potential, and anything less is a waste of talent and a blemish on human dignity and flourishing [61]. The writer [33] goes further to argue that even those who are partial toward the excellence side of the equality-excellence nexus will see that, until a fair level of excellence is achieved, equality is a chimera. In terms of order of priority, [33] argued that indeed, equality is a significant one, but simply a lay-bye along the way toward self-actualization. Equity would occur when each individual's specific educational needs were met, and the individual could progress as far as his or her abilities allowed. In this sense it has been argued that the achievement of equality, in and of itself, turns out to be a pyrrhic victory, a triumph without benefit to the winners [33]. This paper shares the view that educational equity, means providing children, and especially poor children, with excellence—excellent instruction, excellent curricula, excellent teachers, excellent tutoring, excellent enrichment [61]. For high-potential children from underrepresented groups in particular, it means identifying their talent early, cultivating it through gifted-and-talented programs and keeping them on a trajectory of high achievement all the way through high school and beyond. Failure to perceive that metaphysical equality exists in subordination to excellence results in what [62] calls a counterfeit egalitarianism. The view that equality exists in subordination to excellence suggests that once excellence has been achieved or every child has been enabled to achieve his or her full potential, then equity follows through smoothly and without any effort, yet the reverse order is not true because equity without excellence produces mediocrity, which denies students the equity that we all aspire to [17]. The writer [33] therefore concluded that equality takes precedence over excellence temporally, (which according to Aristotle is *hedonic* happiness) but excellence takes precedence over

equality permanently, as it is the achievement of liberty that alone gives value to freedom or equity, (which according to Aristotle is *eudemonic* happiness).

2.6. How does the natural law theory explain the mathematics crisis

From a natural law perspective, this paper argues that one can explain the problem of continued poor performance in mathematics as well as the consequences suffered thereof. In terms of explaining the persistence of the problem, we note that stakeholders describe the education in South Africa as having improved in recent years, with higher enrollment rates, higher attainment rates, better pass rates, and improved literacy. However, in terms of the natural law theory, we argue that this is not consistent with the sustainable education that is premised on the view of enabling students to achieve their maximum potential. If students are not enabled to reach their full potential, then neither equity nor sustainable development has been achieved. Natural law's focus on equity as the highest good has the capacity to provide sensible tools and frameworks within which literacy, competencies, and other educational aspects might be appropriately conceptualized and evaluated against SDG4. Through the natural law theory there is also evidence of an ill-ordered way of choosing pleasure. This is evident in that stakeholders are (a) claiming success of the education system based on access rates which ignore drop-out rates higher than 50% for every cohort since 1994; (b) allowing the protection of incompetent teachers by unions despite earlier research showing that 79% of Grade 6 mathematics teachers could not pass tests aimed at their Grade 6 students; (c) in celebratory mood over improved university enrollments yet a recent 2022 assessment of primary school mathematics teachers showed that first-year B. Ed students across three universities scored 52% on a primary school maths test and final-year B. Ed students scored 54%; (d) describing international progress based on lowered benchmarks [below 400] on the international competitions instead of allowing students to compete with their peers at the same internationally set standards; (e) continuing to field year-older students on the international competitions instead of fielding same age students; (f) describing education as a system on the rise using national pass rates based on exceedingly low bars instead of top-end performances that empower students going further.

In all this, one could also see how stakeholders are violating natural law because by nature, we do not improve learner performance by lowering standards, nor do we do so by protecting incompetent teachers. These decisions suggest that authorities are pursuing a short-term good/happiness rather than a long-term moral good/true happiness in accordance with nature. This provides the nation with temporary happiness instead of true happiness which according to Aristotle is *hedonic* happiness instead of *eudemonic* happiness. Similarly, Locke states that the kinds of pleasures that we experience in connection to such temporary pleasure are ephemeral and not representative of complete happiness.

In terms of consequences of violating the natural law; contrary to the perception that natural law is a mere abstraction without practical consequences, [52] says the features of the law of nature can be discovered by anyone who is diligent about directing their mind to them, and can be concealed from no one "unless he loves blindness and darkness and casts off nature in order that he may avoid his duty".

Several theorists confirm that the natural law is a mandatory rule of action which has a profound influence on the life of every living person. For example, [37] notes that he is not the first theorist to write on natural punishment citing others such as Immanuel Kant, John Locke, Jacques Derrida, and Doug Husak just to name a few. Similarly, the mere fact that the United Nations General Assembly endorsed the concept of crime against humanity (CAH) in 1946 bears testimony to a global recognition of violation of natural law and its punishment. However, the endorsement of a crime against humanity by the UN comes long after a nation has suffered natural punishment and in most cases the suffering is never recognized as a CAH. Hence critics warn that unlike genocide and war crimes, which have been widely recognized and prohibited in international criminal law since the establishment of the Nuremberg principles, there is a need for comprehensive attention to crimes against humanity which are continuously perpetrated worldwide in numerous conflicts and crises. At the latest UN Security Council meeting in 2023, the secretary general acknowledged these crimes and noted with concern that six out of seven countries worldwide are plagued by feelings of insecurity and 2 billion people live in places affected by such conflicts. The secretary stressed that there was only one route to durable peace—the route of sustainable development.

In order to see how education is central to all these problems born of violation of natural law in South Africa, let us start by asking for the purpose of education. From education experts three main goals tend to stand out: (a) to prepare individuals to be active citizens in their communities and foster social cohesion; (b) to facilitate the acquisition of knowledge and skills necessary for the economy and, ultimately, to a society's development; (c) to build an individual's identity and autonomy and enable them to exercise their freedom. The passport to your future," "the most powerful weapon," "the key to unlocking the world"—these are just a few of the many ways education has been described. The reader could easily notice the links between the educational goals and Aristotle's concept of *eudemonic happiness.* From the very first philosophers of education, happiness was one of the central aims of education and to date happiness is closely related to education, which is often portrayed as one of the key (direct or indirect) aims of education. Yet the latest World Happiness Report places South Africa in the bottom 6 out of 36 sub-Saharan countries and 106 out of 149 countries globally [63]. Studies have shown that happiness can promote socially desirable behaviors, and these socially desirable behaviors continue to be revered to date given that education is described as the process of bringing desirable changes into the behavior of human beings. On the other hand, lack of happiness or stress promotes socially undesirable behaviors. For example, [64] identified stress as one of the drivers of learner aggression in South African schools. There is also a societal component to stress as well since the quality of society is determined by the quality of its citizens and when individual citizens of society are stressed, one can say that the "collective consciousness" is characterized by stress. Just as individual stress has been scientifically linked to a wide range of diseases, similarly, epidemic levels of societal stress have been linked to the widespread rise of social disorders: Crime, drug abuse, family disintegration, domestic violence, and the decline of moral and social values. For example, South Africa has a high crime rate, with a crime index of 75.4 in 2024. It is considered the most dangerous country in Africa and the fifth most dangerous in

the world. In 2022 the murder rate was 45.53 per 100,000 people, the fourth highest in the world, according to the United Nations Office for Drugs & Crime (UNODC). This rising stress, in turn, contributes to further violations of natural law by the individual and society and in South Africa it has eroded academic outcomes, increased drug usage, and raised juvenile crime and violence, particularly in the higher education institutions, to record levels.

2.7. Implications of the natural law theory for gifted education

In order to understand the implications of Aristotle's natural law theory for gifted education and sustainable development, it is important to note his original idea of functionings and capability; defined as "the commodities over which a person can establish her ownership and command". According to Aristotle, the best political arrangement is that according to which anyone whatsoever might do their best and live a flourishing life (*zoie makarios*). In this regard it is useful to look at the contribution of education to enable individuals to function as equal democratic citizens when conducting their lives in modern societies. The relation between the capability perspective and education is acknowledged in the 2002 UNESCO Report "Education for all"—where sustainable education for sustainable development is premised on the view that people are a creative resource, and this creativity is an asset societies must tap. To nurture and enhance that asset, education must be provided to help students become more capable and creative, skillful, productive, and better able to deal with day-to-day problems. Researchers who have applied the capability approach to educational settings identified two groups of inputs or conversion factors, some of which are internal to the student while others are external. The conversion argument says that the importance of primary goods or resources [external conversion factors] is derivative on the individual capability [internal conversion factors] to convert them into valued functionings, suggesting that educational outcomes are not homogenous but depend on the student's potential and motivation. The recommendation from such studies is that there is a critical component of our capability that the system has neglected for decades—the gifted learners who have the potential to become the scientists and engineers that are needed in the KBE.

The last question of this paper has to do with the need to suggest the way forward in terms of addressing the South African mathematics crisis. The [65] report captures the importance very well through this metaphor: *If your bicycle tire has a hole, pumping in more air will not do much good. This is not because you do not need air in the tire; it is because you must fix the hole first and then add the air. Pumping more books, more teachers, or more training into existing systems is just a palliative measure.* So how does this paper propose to fix the holes in the South African mathematics crisis.

We have seen how excellence takes precedence over equity but how is excellence achieved? Locke points to a basic principle of human development that something less perfect cannot bring more perfect things into existence. "The blind leading the blind" is an idiom that describes a situation where someone who is not knowledgeable about a subject is giving advice or help to another person who is also not knowledgeable about the subject. For time immemorial, human development of any form has

proceeded on the fundamental basis of a critical mass of more knowledgeable others (excellence) imparting knowledge or skills to mentees, trainees, or students. Similarly, in Aristotle's philosophy, the Greek word (sophos), 'a wise man' is related to the noun, (sophia), 'wisdom' which commonly referred to an expert in his profession or craft. Charioteers, sculptors, or military experts could be referred to as (sophoi) in their occupations and in **Figure 3**, we provide an example of how gifted people or excellence are used in any form of human development to create a chain of knowledge transfer within an organization or society.

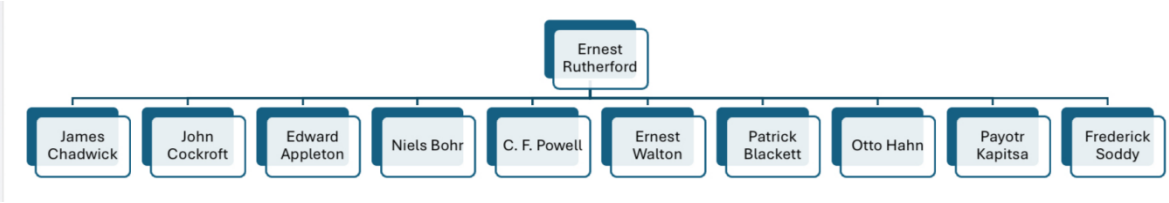

Figure 3. A tree diagram showing Ernest Rutherford and his Nobel Laureates [own compilation].

We use Ernest Rutherford (ER) who won the Nobel Prize for chemistry in 1908 and who is among the greatest scientists in history. He also made an outstanding contribution by producing 11 Nobel Laureates under his supervision as shown in **Figure 3**. Besides the 11 Nobel Laureates, Rutherford supervised many other students whose performances are not on record. However, assuming each of the Nobel Laureates together with the other students produced the same number of such scientists one can see how quickly equity in education would be achieved through excellence. This is what drove [66] in all his work on intelligence way back in the 19th century. He emphasized that research in gifted education should be a human endeavor worth pursuing—because excellence for some translates into equity for all.

3. Conclusion

This paper has argued through the natural law theory that excellence precedes and is therefore an antidote for equity. Natural law defines this equity more precisely as achieving the highest good or excellence. In education, the natural law theory suggests that students' internal factors, such as their potential and motivation, must be prioritized before external resources are provided because education must enable the achievement of people's full potential. In this regard, gifted education should form part of a sustainable development agenda for any country. Hence viewing gifted education as elitist is detrimental to achieving sustainable education, especially in the mathematical sciences.

In terms of practice, the natural law suggests that excellence for some is the route to achieving equity for all. In South Africa, the founding rationale of the Dinaledi or 'star' schools was to enable a nucleus of well-functioning schools to act as mentor-trainers of neighboring schools and to allow them to follow suit [67]. A synonym for mentor is a 'wise man' denoting someone who has a higher level of knowledge than the other (mentee) and here is a clear admission on the department of education that excellence for some should come before equity for all. In fact, [68] warned that in education elevating equity over excellence as a matter of principle was not

implementable because by definition, a critical mass of people with higher levels of knowledge and skill (excellence) are needed to educate others. That the country allows the teachers union to protect teachers who failed a test meant for their Grade 6 students is in itself self-destructive because the more numerous and proficient (excellent) the trainers/mentors/teachers are, the more rapidly equity can be achieved for the population at large. In fact, [69] emphasizes that point through an analogy wherein mathematical science interventions in the absence of knowledgeable others are likened to accelerating a car through wheel-spinning mud, lacking the essential element that provides the traction needed to make them effective. In fact, there is evidence to show that gifted education is what lifted Singapore's standards, given that the country's vision was to build an inclusive society with many peaks of excellence [70]. The take-home and crucial point in this paper is that instead of equity for all coming before excellence for some, it must be excellence for some coming before equity for all; otherwise, equity would never be achievable in South Africa and many other countries with similar challenges.

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Review

Medical social work in hospice settings: Bridging clinical care and emotional support

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Abstract: Medical social workers play an indispensable role in hospice settings by addressing the multifaceted needs of patients and their families during end-of-life care. This paper focuses on how their expertise in psychosocial assessment, care planning, advocacy, counseling, and resource coordination ensures holistic, patient-centered care that integrates clinical and emotional support. Medical social workers foster culturally sensitive practices through interdisciplinary collaboration, enhance communication among care teams, and provide tailored interventions that address emotional, social, and spiritual concerns. This integration improves the quality of life for patients and alleviates emotional and systemic burdens on healthcare infrastructures. In addition to their immediate contributions, medical social workers support sustainable healthcare systems by promoting health equity and addressing disparities in hospice care. Their work aligns with global Sustainable Development Goals (SDGs), particularly SDG 3 (Good Health and Well-being) and SDG 10 (Reduced Inequalities), by ensuring equitable access to compassionate care for marginalized populations. Furthermore, their efforts to empower communities, advocate for cost-effective care strategies, and integrate social and medical perspectives contribute to the long-term resilience of healthcare systems. As the healthcare landscape evolves, the role of medical social workers in hospice care becomes increasingly critical. Their ability to address root causes of distress, navigate complex family dynamics, and facilitate interdisciplinary collaboration exemplifies the necessity of their role in advancing equitable and effective end-of-life care.

Keywords: medical social work; hospice care; psychosocial assessment; health equity; sustainable healthcare; emotional support; holistic care

1. Introduction

Hospice care is fundamentally centered on providing comfort and dignity to terminally ill patients and their families. This approach is rooted in the philosophy that the end of life should focus on quality rather than quantity of life, emphasizing symptom management, emotional support, and spiritual care. Studies have shown that hospice enrollment not only enhances the quality of care but also leads to significant cost savings for healthcare systems, particularly Medicare, by reducing hospitalizations and improving patient satisfaction [1]. The holistic nature of hospice care integrates various aspects of patient well-being, ensuring that physical and emotional needs are addressed. This comprehensive approach is essential for creating a supportive environment where patients can experience a dignified end-of-life journey.

Medical social workers play a crucial role in the hospice care framework, providing essential psychosocial support that complements clinical interventions. Their expertise allows them to address the multifaceted needs of patients and families, including emotional, social, and spiritual concerns [2]. Research indicates that social workers are instrumental in conducting psychosocial assessments that inform care plans and ensure patients' needs are holistically met [3]. By integrating clinical care with emotional and psychosocial assistance, social workers help alleviate the burdens families face during this challenging time. Their involvement not only enhances the quality of life for patients but also supports family dynamics, fostering resilience and coping strategies that are vital during the grieving process.

The emotional and psychological dimensions of hospice care cannot be overstated. Social workers are trained to recognize and address the emotional turmoil that often accompanies terminal illness, providing counseling and support to both patients and their families [4]. This support is crucial as families navigate the complexities of end-of-life decisions and the emotional weight of impending loss. Furthermore, social workers facilitate communication among family members and healthcare providers, ensuring that everyone is aligned in their understanding of the patient's wishes and care goals. This collaborative approach improves the quality of care and enhances the overall experience for families, as they feel more informed and supported throughout the process.

Navigating the healthcare system can be particularly daunting for families facing terminal illnesses, and social workers serve as vital navigators in this complex landscape. They assist families in understanding their options, accessing resources, and advocating for their loved ones' needs within the healthcare system [5]. This advocacy is especially important in hospice care, where families may encounter barriers related to insurance coverage, service availability, and communication with healthcare providers. By addressing these systemic challenges, social workers help ensure that patients receive the care they deserve, ultimately improving outcomes and satisfaction levels for patients and their families.

The interdisciplinary nature of hospice care is another critical aspect of its effectiveness. Social workers collaborate with diverse healthcare professionals, including physicians, nurses, and chaplains, to create comprehensive care plans tailored to each patient's unique needs [6]. This team-based approach allows for a more thorough assessment of the patient's condition, involving medical needs and emotional and spiritual dimensions. Research has shown that effective communication and collaboration among team members lead to better patient outcomes and higher family satisfaction rates [7]. The integration of social work into the hospice team enhances the overall quality of care and ensures that all aspects of the patient's experience are considered.

Despite the many benefits of hospice care, challenges persist in the delivery of these services. Issues such as burnout among healthcare providers, including social workers, can impact the quality of care provided [8]. High levels of emotional strain and the demands of working with terminally ill patients can lead to decreased job satisfaction and effectiveness. Addressing these challenges is essential to maintaining a robust hospice workforce capable of delivering high-quality care. Organizations

must prioritize the well-being of their staff through support systems, training, and resources that enable them to cope with the emotional demands of their roles.

The impact of medical social workers in hospice care extends beyond individual patient interactions; it also contributes to the sustainability of healthcare systems as a whole. By improving the quality of end-of-life care, social workers help to reduce unnecessary hospitalizations and emergency room visits, which can strain healthcare resources [9]. Furthermore, their role in facilitating advance care planning and discussions about end-of-life preferences can lead to more appropriate care decisions, aligning treatment with patients' values and wishes. This alignment enhances patient satisfaction and promotes more efficient use of healthcare resources, ultimately benefiting the broader healthcare system.

Hospice care focuses on comfort, dignity, and quality of life for terminal patients. Research shows hospice enrollment reduces hospitalizations and cuts healthcare costs significantly. Medical social workers provide crucial emotional and psychosocial support for patients and families. They help navigate complex healthcare systems, advocating for necessary resources and care. The interdisciplinary team approach in hospice care improves patient outcomes and family satisfaction.

This paper explores the vital role of medical social workers in hospice settings, emphasizing their contributions to bridging clinical care and emotional support for patients and families. It highlights their multidisciplinary collaboration, ability to address psychosocial challenges and advocacy for equitable access to resources. Additionally, it examines how their work aligns with sustainable development goals, fostering long-term resilience in healthcare systems.

2. The role of medical social workers in hospice care

2.1. The essential role of medical social workers in hospice care

The role of medical social workers in hospice care is multifaceted and essential for providing holistic support to patients and their families during the end-of-life process. Medical social workers are trained professionals who engage in various activities that address patients' and their families' emotional, social, and financial needs. **Figure 1** presents the role of medical social workers in hospice care.

Figure 1. The role of medical social workers in hospice care.

2.1.1. Psychosocial assessments and care planning

One of the primary responsibilities of social workers in hospice care is conducting psychosocial assessments. These assessments are crucial for evaluating the emotional and social situations of patients and their families, which allows for the development of tailored care plans that address individual needs. Research indicates that patients and families value the comprehensive support provided by hospice services, including medical care and psychological and social assistance [10]. This holistic approach ensures that care plans are both medically sound and sensitive to the emotional and social dynamics at play during this challenging time [11].

In addition to psychosocial assessments, medical social workers play a vital role in care planning. They collaborate with interdisciplinary healthcare teams to develop comprehensive care strategies that address medical and emotional needs. Effective communication among team members is essential for ensuring that all aspects of a patient's care are considered [12]. However, studies have shown that there are often deficiencies in collaboration during care planning discussions, with social workers' contributions needing to be more utilized [13]. This lack of integration can lead to gaps in care that may negatively impact patient outcomes. Therefore, enhancing the role of social workers in interdisciplinary team meetings is crucial for improving the overall quality of hospice care [14].

2.1.2. Advocacy

Advocacy is another critical function of medical social workers in hospice settings. They advocate for patients and families, ensuring they have access to essential resources such as financial aid, community services, and legal support. This advocacy is essential for vulnerable populations facing additional healthcare barriers [15]. Social workers are trained to recognize these issues and work collaboratively with healthcare providers to address them, thereby improving health outcomes and the quality of the dying experience [16]. By facilitating communication between patients and the medical team, social workers help ensure that patients' needs and preferences are respected and met throughout the hospice process [17].

2.1.3. Counseling

Counseling is fundamental to the support that medical social workers provide to patients and families in hospice care. They offer emotional support to help individuals cope with grief, stress, and the complexities of end-of-life decisions. The emotional toll of terminal illness can be overwhelming, and social workers are equipped to provide the necessary support to navigate these challenges [18]. Research has shown that social workers play a significant role in addressing the psychological needs of patients and their families, which can lead to improved coping mechanisms and overall well-being [19]. This emotional support is vital in helping families cope with impending loss and facilitating discussions about end-of-life preferences and decisions.

2.1.4. Resource coordination

Resource coordination is another essential function of medical social workers in hospice care. They connect patients and families with community resources, such as support groups and home care services, to enhance the quality of life during the

hospice experience. This coordination is essential for ensuring patients receive comprehensive support beyond medical care [20]. Studies have highlighted the importance of social workers in facilitating access to these resources, which can significantly improve the overall hospice experience for patients and their families [21]. By linking families with appropriate community services, social workers help alleviate some of the burdens associated with caregiving and enhance the quality of life for patients and their caregivers.

2.2. Addressing challenges and enhancing the role of social workers in hospice care

The challenges faced by medical social workers in hospice care are significant and multifaceted. Issues such as limited information sharing in interdisciplinary team meetings, inadequate time during home visits, and a lack of clinical tools to assess caregivers' attitudes and competencies can hinder their effectiveness [12]. Moreover, the emotional demands of the role can lead to burnout and compassion fatigue among social workers, which can ultimately impact the quality of care provided to patients [20]. Addressing these challenges requires systemic changes within hospice organizations to ensure that social workers are adequately supported and integrated into the care team [17].

Training and education for social workers in hospice settings are also critical for enhancing their effectiveness. Research indicates that many social workers (may be) unprepared to address spiritual issues in end-of-life care, an essential component of holistic care [11]. Providing targeted training that focuses on the spiritual dimensions of care can empower social workers to better support patients and families in navigating these complex issues. Furthermore, ongoing professional development opportunities can help social workers stay informed about best practices and emerging trends in hospice care [22].

The integration of social work into hospice care is not only beneficial for patients and families but also for the healthcare system as a whole. Studies have shown that when supported by social work, hospice care leads to improved patient outcomes, including reduced symptom distress and enhanced quality of life [23]. Additionally, hospice care has been associated with lower healthcare costs and reduced reliance on hospital-based resources, underscoring the importance of comprehensive care models, including social work [24]. By advocating for the inclusion of social workers in hospice teams, healthcare organizations can enhance the overall effectiveness and efficiency of care delivery.

3. Interdisciplinary collaboration in hospice settings

Interdisciplinary collaboration in hospice settings is essential for delivering comprehensive, patient-centered care. Integrating diverse healthcare professionals, including physicians, nurses, chaplains, and therapists, creates a holistic approach to managing the complex needs of patients at the end of life. This collaborative model enhances the quality of care provided and fosters a supportive environment for patients and their families. Research indicates that when hospice aides are validated and integrated as interdisciplinary team members (IDT), the overall quality of patient and

family care improves significantly, alongside job satisfaction and retention among aides [25]. Including various professionals ensures that all aspects of a patient's care—medical, emotional, and spiritual—are addressed, leading to better outcomes and a more dignified end-of-life experience. **Figure 2** presents the interdisciplinary collaboration in hospice settings.

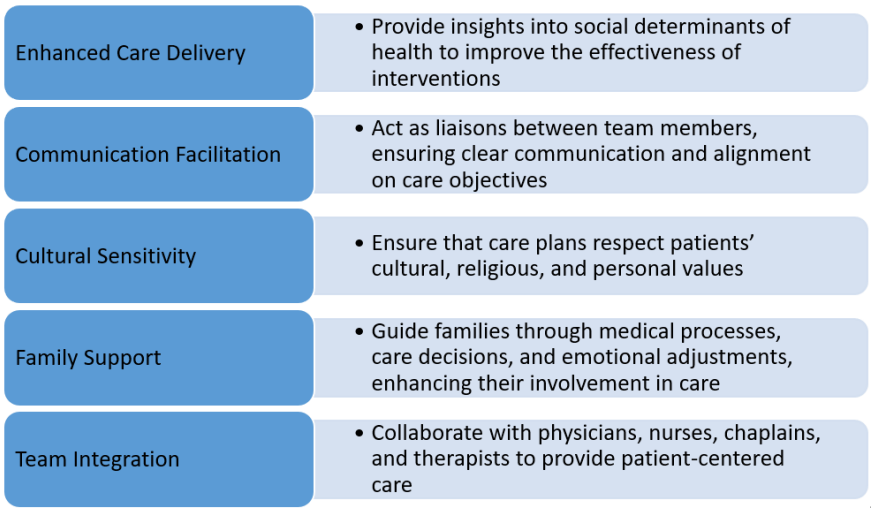

Figure 2. The interdisciplinary collaboration in hospice settings.

3.1. Cultural sensitivity

Cultural sensitivity is a critical component of effective hospice care, as it ensures that care plans respect and reflect patients' cultural, religious, and personal values. The diverse backgrounds of patients necessitate a tailored approach that recognizes individual beliefs and practices. For instance, studies have shown that the emotional and spiritual needs of Hispanic families in hospice settings require particular attention and understanding [26]. By training healthcare professionals in culturally competent practices, hospices can better serve minority populations and address disparities in care [27]. Furthermore, integrating community health workers, such as promotor as de salud, has proven effective in enhancing health education and access to resources for underserved populations [26]. This culturally sensitive approach improves patient satisfaction and fosters trust and rapport between healthcare providers and families.

3.2. Effective communication

Effective communication is paramount in hospice settings, where the stakes are high, and decisions often involve complex emotional and ethical considerations. Acting as liaisons between team members, hospice social workers, and other professionals facilitates clear communication and alignment on care objectives. Research highlights that videoconferencing can enhance communication among family caregivers and hospice teams, improving emotional support and developing family-oriented care plans [28]. Additionally, hospice staff members have reported challenges related to communication, particularly regarding the roles of psychosocial and spiritual care providers, which often need to be understood or utilized [17]. Addressing these communication barriers is essential for ensuring that all team members are on the same page and that patients receive coordinated care.

3.3. Enhanced care delivery

Understanding social determinants of health significantly influences the delivery of enhanced care in hospice settings. These determinants, including socioeconomic status, education, and access to healthcare, play a crucial role in shaping health outcomes. Research suggests continuous support services, including in-home assistance for family caregivers, can mitigate socioeconomic disparities and reduce unplanned hospitalizations [29]. By providing insights into these determinants, hospice teams can tailor interventions to meet the specific needs of their patients, ultimately improving the effectiveness of care delivery. This approach aligns with the World Health Organization's definition of palliative care, which emphasizes the importance of addressing the broader context of a patient's life and medical needs [30].

3.4. Family support

Family support is another vital aspect of interdisciplinary collaboration in hospice care. Families often face significant emotional and logistical challenges as they navigate medical processes and care decisions for their loved ones. Hospice professionals are crucial in guiding families through these complexities, enhancing their involvement in care and decision-making [29]. Research indicates that family caregivers are integral to the care of hospice patients, providing essential support that can prevent crises and hospitalizations [29]. By equipping families with the necessary knowledge and resources, hospice teams can empower them to take an active role in their loved one's care, ultimately leading to better patient and family outcomes.

3.5. Team integration

The integration of diverse healthcare professionals in hospice settings also addresses the unique needs of specific populations, such as children and racial/ethnic minorities. Pediatric hospice care, for instance, requires specialized knowledge and approaches to meet the distinct needs of young patients and their families [31]. Studies have shown that telemedicine can enhance pediatric palliative care, allowing for better family communication and support [31]. Similarly, research highlights the importance of community outreach and collaboration with local organizations to improve access to hospice services for racial and ethnic minorities [27]. By recognizing and addressing the unique challenges faced by these populations, hospice teams can provide more equitable and effective care.

Moreover, the role of pharmacists within hospice interdisciplinary teams must be considered. Pharmacists contribute significantly to patient care by ensuring appropriate medication management, which is crucial in palliative settings where symptom control is a priority [30]. Their expertise in pharmacotherapy allows for more effective pain management and the alleviation of distressing symptoms, ultimately enhancing the quality of life for hospice patients. The integration of pharmacists into the IDT underscores the importance of a comprehensive approach to care that includes all relevant healthcare professionals.

Despite the benefits of interdisciplinary collaboration, challenges must be addressed when implementing effective team practices in hospice settings. Staff members often report feeling overwhelmed by regulatory constraints and the

complexities of coordinating care among various team members [17]. Additionally, the perception that specific roles, such as those of chaplains and social workers, are undervalued can hinder effective collaboration [17]. Addressing these challenges requires ongoing training, policy reforms, and a commitment to fostering a culture of teamwork and mutual respect among all hospice team members. Technology has also transformed the landscape of hospice care, facilitating better communication and collaboration among team members. Electronic health records (EHRs) allow for more efficient patient information sharing, enabling team members to stay informed about care plans and progress [32]. Furthermore, integrating telehealth services has expanded access to care, particularly for patients in remote areas or those with mobility challenges [33]. By leveraging technology, hospice teams can enhance their ability to provide timely and effective care, ultimately improving patient outcomes.

4. Challenges and enhancing support for medical social workers in hospice care

4.1. Challenges in hospice medical social work

The hospice medical social work field faces numerous challenges that significantly impact the quality of care provided to patients and their families (**Figure 3**).

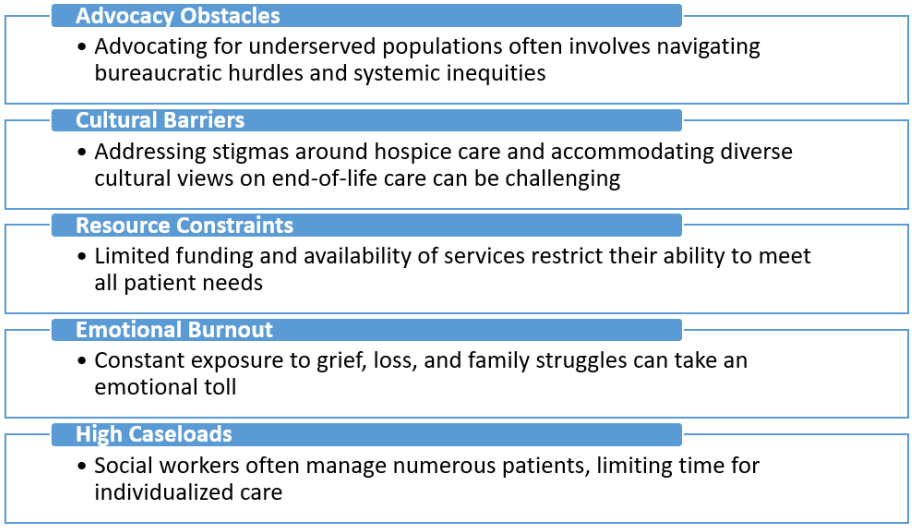

Figure 3. Challenges in hospice medical social work.

4.1.1. High caseload

One of the most pressing issues is the high caseloads that social workers must manage. Social workers in hospice settings often juggle numerous patients simultaneously, which restricts their ability to provide individualized care. This situation is exacerbated by financial pressures within the healthcare system, as highlighted by Cabin, who notes that the financial calculus in hospice care increasingly prioritizes profit over patient care, compromising the quality of services offered to patients and their families [34]. The inability to dedicate sufficient time to each patient

can hinder the development of meaningful relationships, which is crucial in providing effective end-of-life care.

4.1.2 Emotional burnout

Emotional burnout is another significant challenge faced by hospice social workers. The nature of their work exposes them to constant grief, loss, and the emotional struggles of families dealing with terminal illnesses. Research indicates that the emotional toll of such exposure can lead to burnout, negatively affecting the workers' mental health and ability to perform their duties effectively [18]. The cumulative effect of witnessing death and supporting grieving families can create a cycle of emotional fatigue that is difficult to break. This phenomenon is further compounded by the high demands placed on social workers, including the need to support distraught family members while managing their grief [18]. The emotional burden can lead to decreased job satisfaction and increased turnover rates among social workers in hospice settings.

4.1.3. Resource constraints

Resource constraints are a critical barrier to practical hospice social work. Limited funding and the availability of services restrict social workers' ability to meet all patient needs adequately. Teno's research highlights how financial considerations often overshadow patient care, resulting in inadequate support for patients and their families [34]. The lack of resources can manifest in various ways, including insufficient staffing, limited access to necessary services, and inadequate training opportunities for social workers. These constraints can ultimately compromise the quality of patient care, as social workers need more support to navigate the complexities of end-of-life care.

4.1.4. Cultural barriers

Cultural barriers also pose significant challenges in hospice medical social work. Addressing stigmas surrounding hospice care and accommodating diverse cultural views on end-of-life care can be difficult. Yapp [35] emphasized that cultural perceptions can influence family reluctance to accept hospice referrals, often leading to late referrals that negatively impact the quality of care received. Additionally, the need for culturally competent care is paramount, as social workers must navigate various cultural beliefs and practices related to death and dying. This complexity is further complicated by language barriers and differing family dynamics, which can hinder effective communication and understanding between social workers and patients or their families [36].

4.1.5. Advocacy

Advocacy for underserved populations is another area fraught with challenges. Social workers often find themselves advocating for patients who belong to marginalized communities, which requires navigating bureaucratic hurdles and systemic inequities. The work of Gardner et al. [37] underscored the racial and ethnic disparities in palliative care, highlighting the need for social workers to advocate for equitable access to services. However, the bureaucratic nature of healthcare systems can create obstacles that hinder effective advocacy, making it difficult for social workers to secure the necessary resources and support for their patients. This situation

is further complicated by the intersection of various social determinants of health, which can exacerbate existing disparities in access to care.

4.2. Strategies to support and enhance the effectiveness of medical social workers in hospice care

Several solutions have been proposed (**Figure 4**). Organizational support through counseling and resilience training can help social workers cope with the emotional demands of their work. Providing access to mental health resources and promoting a culture of self-care within hospice organizations can mitigate the effects of burnout and improve job satisfaction among social workers [18]. Furthermore, policies promoting manageable workloads and work-life balance are essential in ensuring social workers can provide high-quality care without compromising their well-being. Implementing strategies that allow for flexible scheduling and adequate patient interaction time can enhance hospice social work's overall effectiveness.

Figure 4. Solutions to the challenges in hospice medical social work.

Increased funding and community partnerships are also crucial for expanding resources available to hospice social workers. Collaborating with community organizations can help bridge service gaps and provide additional support for patients and their families. For instance, partnerships with harm reduction programs can improve access to end-of-life care for marginalized populations, such as those experiencing homelessness or substance use disorders [38]. By fostering these collaborations, hospice social workers can enhance the continuum of care and ensure that patients receive comprehensive support throughout their end-of-life journey.

Cultural competence training is vital for social workers to navigate the diverse cultural landscapes of their patients effectively. Education on cultural beliefs and practices related to death and dying can empower social workers to deliver more personalized and respectful care [39]. Creating an inclusive environment that values diverse perspectives also helps address the cultural barriers that often hinder effective communication and understanding in hospice settings. As noted by Milberg et al., understanding cross-cultural interactions is essential for improving the quality of end-of-life care [40]. By equipping social workers with the necessary skills and knowledge,

healthcare organizations can foster a more culturally sensitive approach to hospice care.

5. Emotional and ethical dimensions of hospice care

The emotional and ethical dimensions of hospice care represent a complex interplay of patient autonomy, family dynamics, and healthcare ethics (**Figure 5**).

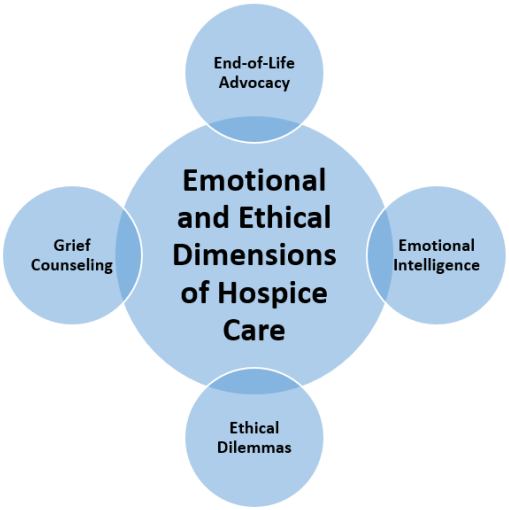

Figure 5. Emotional and ethical dimensions of hospice care.

5.1. Ethical dilemma

The ethical dilemma of balancing patient autonomy with medical recommendations and family preferences is a significant concern in hospice care. Patients in this setting often confront critical decisions regarding their treatment options, which are deeply influenced by their values and beliefs. Confidentiality and voluntariness cannot be overstated in this context, as they are fundamental to respecting patient autonomy. Research indicates that effective communication among healthcare providers, patients, and families is crucial in navigating these dilemmas, fostering understanding and respect for the patient's wishes while addressing family concerns [7,41–43]. The ethical principle of informed consent is predicated on the notions of autonomy, voluntariness, and the absence of coercion, which are essential for patients to make decisions that align with their values [44,45]. In hospice care, where decisions often involve end-of-life considerations, ensuring patients feel free to express their preferences without undue influence from family members or medical staff is vital for ethical practice [46]. This dynamic underscores healthcare professionals' need to cultivate an environment where patients feel secure in their choices, thereby enhancing the quality of care and patient satisfaction [47].

Moreover, the ethical dimensions of hospice care extend to issues of access and equity, particularly for marginalized populations such as undocumented immigrants, who may face significant barriers to accessing hospice services. These barriers can exacerbate suffering and complicate end-of-life care, highlighting the need for healthcare systems to address disparities and ensure equitable access to quality hospice care for all patients, regardless of their background [48,49]. Advocacy efforts to

improve access to hospice services for these populations are essential in upholding the ethical principles of justice and equity in healthcare [50]. The interplay between patient autonomy, confidentiality, and the moral obligation to provide equitable care illustrates the complexity of decision-making in hospice settings. By prioritizing these ethical considerations, healthcare providers can better support patients and their families during one of the most challenging times, ultimately fostering a more compassionate and just healthcare system [51].

5.2. Emotional support and intelligence

The emotional support provided to patients and their families is paramount in hospice settings. Studies have shown that emotional support correlates positively with satisfaction in hospice care, emphasizing the need for healthcare providers to be attuned to the emotional states of their patients and families [41,52]. The provision of anticipatory grief counseling is essential in helping families manage their emotions as they prepare for the impending loss of a loved one. This support can significantly alleviate the psychological burden associated with the dying process, allowing families to engage in meaningful conversations and farewells [41,53]. Moreover, post-loss bereavement support is equally important, as it aids families in navigating their grief and adjusting to life after loss, which can be a prolonged and challenging journey [53].

Emotional intelligence plays a critical role in hospice care, particularly in the context of empathy and active listening. Healthcare providers must cultivate these skills to effectively address the concerns of patients and their families [54]. Empathy in hospice care is not merely a professional obligation but an essential component of the therapeutic relationship that fosters trust and openness [54]. By actively listening to patients and families, providers can better understand their needs and preferences, vital for delivering patient-centered care. This approach not only enhances the quality of care but also contributes to the emotional well-being of both patients and their families [54].

5.3. End-of-life advocacy

End-of-life advocacy is another crucial aspect of hospice care, as it empowers patients to make informed decisions regarding their treatment options, including advance directives and palliative care choices. Research indicates that patients well-informed about their options are more likely to discuss their care preferences, leading to better alignment between their wishes and the care they receive [55]. This advocacy is critical in diverse populations where cultural and religious beliefs may influence end-of-life decisions [56]. Healthcare providers must be equipped to navigate these complexities and ensure patients' voices are heard and respected throughout the decision-making process [55].

5.4. Conflict mediation

Conflict mediation is often necessary in hospice care settings, mainly when family disagreements arise regarding care approaches. These conflicts can stem from differing opinions about treatment options, the appropriateness of hospice care, or the patient's wishes [57]. Effective conflict resolution strategies are essential to ensure

that care remains patient-centered and the patient's autonomy is upheld. Research highlights the importance of facilitating open communication among family members and healthcare providers to address misunderstandings and foster collaborative decision-making [57]. By mediating conflicts, healthcare providers can help families reach a consensus and honor patients' preferences.

The role of healthcare providers in hospice care extends beyond clinical responsibilities; they must also act as emotional support systems for patients and families. This dual role requires providers to be sensitive to the emotional and psychological needs of those they care for [41,52]. Studies have shown that families who receive adequate emotional support during the hospice process report higher satisfaction levels with the care provided [7,41]. This underscores the importance of training healthcare professionals in emotional intelligence and communication skills, enabling them to provide holistic care that addresses the dying process's physical and emotional aspects [41,52].

Moreover, the integration of grief counseling into hospice care is essential for supporting families through the anticipatory grief process. Anticipatory grief can manifest as a range of emotions, including sadness, anger, and anxiety, as families prepare for the loss of a loved one [41,53]. Providing families with tools and resources to cope with these emotions can significantly enhance their overall experience in hospice care. Research suggests that families who engage in grief counseling are better equipped to manage their feelings and navigate the complexities of loss, ultimately leading to healthier grieving processes [41,53].

6. Implications for sustainable development

The implications for sustainable development, particularly in health equity and access to quality hospice care, are multifaceted and critical for achieving the Sustainable Development Goals (SDGs) (**Table 1**). One of the primary objectives is to ensure that vulnerable populations, including marginalized groups, have equitable access to quality hospice care. This is particularly relevant to SDG 3, which emphasizes good health and well-being, and SDG 10, which focuses on reducing inequalities. Research indicates that social support systems significantly enhance healthcare accessibility, especially for older adults who often face geographic and economic barriers to care [58]. By fostering community-based support systems, we can mitigate these barriers, thereby promoting health equity and improving overall well-being.

Table 1. Implications of medical social work in hospice care for sustainable development.

Aspect	Key Focus	Impact
Health Equity	Ensuring vulnerable populations have equitable access to quality hospice care.	Improves fairness in healthcare delivery and addresses disparities for underserved communities.
Contributions to SDGs	SDG 3: Promotes physical and mental well-being through holistic care. SDG 10: Addresses inequalities in end-of-life care for marginalized groups.	Aligns hospice practices with global goals for health and reduced inequalities.
Community Empowerment	Strengthening community-based support systems to reduce reliance on formal healthcare infrastructures.	Encourages localized care solutions and builds resilience within communities.

Table 1. (*Continued*).

Aspect	Key Focus	Impact
Cost-Effectiveness	Advocating for preventive and palliative measures to reduce costs associated with prolonged hospital stays.	Eases the financial burden on patients, families, and healthcare systems.
Sustainable Models	Fostering practices that integrate social support with medical care to ensure long-term resilience.	Enhances the durability and effectiveness of healthcare systems to meet future demands.

Moreover, integrating social accountability values into medical education is essential for preparing future healthcare professionals to address diverse populations' needs effectively. Educating medical students about the healthcare system's structure and the importance of preventive care can lead to better health outcomes and resource utilization [59]. This educational approach aligns with the principles of holistic care, which is vital for promoting physical and mental well-being as outlined in SDG 3. By equipping healthcare providers with the necessary knowledge and skills, we can ensure that they are better prepared to serve vulnerable populations, thereby enhancing health equity.

Community empowerment is another critical aspect of sustainable development in healthcare. Strengthening community-based support systems can significantly reduce dependency on formal healthcare infrastructures, which is particularly important in underserved areas. Studies have shown that mobile health clinics can effectively deliver care to impoverished populations, demonstrating the potential of community-driven healthcare initiatives [60]. These initiatives provide essential services and foster a sense of community ownership and involvement in health promotion, which is crucial for sustainable development. Cost-effectiveness is a vital consideration in the context of healthcare sustainability. Advocating for preventive and palliative measures can significantly reduce healthcare costs associated with prolonged hospital stays. Research has demonstrated that meal delivery programs can reduce healthcare utilization among dually eligible Medicare and Medicaid beneficiaries, highlighting the importance of integrating social services with healthcare [61]. Focusing on preventive care and community support can alleviate the financial burden on healthcare systems while improving patient outcomes.

The development of sustainable care models that integrate social support with medical services is essential for ensuring long-term resilience in healthcare systems. Integrated care models have improved access and quality of services, particularly for individuals with complex health needs [62]. By fostering collaboration among healthcare providers, social workers, and community organizations, we can create a more cohesive and effective healthcare delivery system that addresses the diverse needs of patients.

Technology, such as telemedicine, has also shown promise in improving access to hospice and palliative care, particularly for pediatric patients [31]. By leveraging technology to enhance care delivery, we can reach underserved populations more effectively, promoting health equity and improving the quality of care. This approach aligns with sustainable development goals, as it seeks to reduce inequalities in healthcare access. Moreover, community initiatives in healthcare must be considered. Research has shown that family and social support systems significantly influence healthcare access and utilization, particularly among immigrant populations [63]. By

fostering these community ties and support networks, we can enhance healthcare accessibility and promote health equity, essential for sustainable development.

Furthermore, addressing disparities in end-of-life care for marginalized groups is crucial for achieving SDG 10. Research indicates that access to hospice care varies significantly across different populations and is often influenced by socioeconomic factors and systemic barriers [64]. By identifying and addressing these disparities, we can work towards a more equitable healthcare system that ensures all individuals receive the care they need at the end of life. In addition, the role of social workers in integrated healthcare teams is increasingly recognized as vital for addressing the socio-emotional needs of patients, particularly older adults with multiple comorbidities [3,65]. By incorporating social workers into healthcare teams, we can enhance the holistic approach to patient care, ensuring that both medical and social determinants of health are addressed. This integration is essential for promoting health equity and improving overall health outcomes.

Furthermore, integrating social work into sustainable healthcare systems is pivotal for achieving the United Nations Sustainable Development Goals (SDGs), particularly SDG 3, which promotes physical and mental well-being through holistic care, and SDG 10, which addresses healthcare access for marginalized groups. Social workers play a crucial role in bridging gaps in healthcare delivery, advocating for vulnerable populations, and ensuring that healthcare systems are equitable and sustainable. Examples of these are discussed in the subheadings below.

6.1. Nordic countries' sustainable healthcare models

Nordic countries, notably Norway, have established a robust framework for sustainable healthcare that emphasizes environmental management and social equity. All hospitals in Norway are certified under the ISO 14001 environmental management system, which mandates continuous improvement in sustainability practices [66]. Social workers in these settings are integral to implementing holistic care approaches that address physical and mental health needs, thereby contributing to SDG 3. They facilitate access to services for marginalized populations, ensuring that care is culturally competent and sensitive to the unique challenges faced by these groups [66].

6.2. Integrated care models in the UK

In the UK, integrated care systems (ICS) have been developed to enhance collaboration among healthcare providers, including social services. This model aims to provide seamless care that addresses the social determinants of health, essential for promoting well-being [67]. Social workers within ICS play a vital role in coordinating care for individuals with complex needs, ensuring that mental health services are integrated with physical health care. This holistic approach is crucial for achieving SDG 3, as it recognizes the interconnectedness of physical and mental health [67]. Furthermore, social workers advocate for policies that reduce inequalities in healthcare access, particularly for marginalized communities, thus supporting SDG 10 [67].

6.3. Palliative care initiatives in Canada

In Canada, social workers are actively involved in palliative care initiatives that aim to provide equitable end-of-life care. These programs address patients' and their families' emotional, psychological, and social needs, essential for promoting dignity and quality of life during the final stages of life [68]. Research indicates that social workers help reduce disparities in access to palliative care services among marginalized groups, directly contributing to SDG 10 [68]. Their role in facilitating communication between patients, families, and healthcare providers ensures that care is tailored to individual needs, promoting a more humane approach to end-of-life care [68].

6.4. Community health programs in Australia

Australia's community health programs exemplify the integration of social work into sustainable healthcare systems. These programs focus on preventive care and health promotion, particularly in underserved communities [69]. Social workers in these settings engage in outreach efforts to educate individuals about health resources and services, enhancing access to care and promoting overall well-being [69]. By addressing social determinants of health, such as housing and employment, social workers contribute to the holistic care model envisioned in SDG 3. Additionally, their advocacy for policy changes that support marginalized populations aligns with the goals of SDG 10 [69].

6.5. Social work in mental health services in the United States

Social workers are essential in mental health services in the United States, particularly in community-based settings. They provide counseling and support to individuals facing mental health challenges, often exacerbated by socioeconomic factors [70]. Integrating social work into mental health care addresses immediate psychological needs and promotes long-term well-being by connecting individuals with resources that enhance their quality of life [70]. This approach aligns with SDG 3, as it emphasizes the importance of mental health as a component of overall health. Furthermore, social workers advocate for policies that address systemic inequalities in mental health care access, thus contributing to SDG 10 [70].

6.6. Health equity initiatives in South Africa

In South Africa, social workers are at the forefront of health equity initiatives to address the disparities in healthcare access among marginalized populations. These initiatives focus on providing culturally appropriate care and ensuring that healthcare services are accessible to all, regardless of socioeconomic status [71]. Social workers engage in community mobilization efforts to raise awareness about health rights and available services, empowering individuals to seek care [71]. This advocacy is crucial for achieving SDG 10, as it directly addresses inequalities in healthcare access. Moreover, by promoting holistic care that includes mental health support, social workers contribute to the objectives of SDG 3 [71].

6.7. Telehealth innovations in Rural Areas

The rise of telehealth has transformed healthcare delivery in rural areas, where access to services is often limited. Social workers are critical in facilitating telehealth services, ensuring that individuals in remote locations can access physical and mental health care [72]. By providing support and guidance in navigating telehealth platforms, social workers help reduce barriers to care, thereby promoting well-being and health equity [72]. This innovation aligns with SDG 3 by enhancing access to holistic care and supports SDG 10 by addressing inequalities faced by rural populations [72].

Finally, a comprehensive understanding of the social determinants of health is paramount. Addressing social needs, such as food security and housing stability, is increasingly recognized as a critical component of healthcare delivery [73]. By incorporating these social determinants into healthcare planning and policy, we can create a more equitable and sustainable healthcare system that meets the needs of all individuals, particularly those in vulnerable populations.

7. Limitations and future research

The role of medical social workers in hospice care is crucial, yet several limitations in the existing literature highlight significant gaps that warrant further investigation. One of the primary limitations is the insufficient exploration of social workers' contributions within diverse cultural contexts. While cultural competence is recognized as essential in healthcare, empirical studies assessing the effectiveness of social workers' interventions across various cultural groups remain limited. Research indicates that patients' cultural backgrounds can significantly influence their care preferences and outcomes, suggesting that social workers must adapt their approaches accordingly [10]. Furthermore, the long-term effects of social workers' involvement in family dynamics post-patient death are underexplored. Understanding how social workers' support during hospice care translates into sustained benefits for families after the loss could provide valuable insights into the holistic impact of hospice services [74]. Future research should prioritize these areas to enhance social work interventions' cultural relevance and effectiveness in hospice settings.

Another critical gap in the literature pertains to the emotional and physical demands placed on social workers themselves. While studies have documented the high levels of stress and burnout among hospice care workers, there is a lack of comprehensive research focusing on the structural and organizational factors that can mitigate these challenges. For instance, effective supervisory models and organizational support programs could be pivotal in reducing burnout and enhancing job satisfaction among social workers [75]. The COVID-19 pandemic has exacerbated these issues, increasing workloads and emotional strain on hospice workers, highlighting the urgent need for research that identifies effective strategies for supporting these professionals [76]. Additionally, examining the efficacy of interdisciplinary team models in hospice care is essential. Research suggests that social workers often face challenges in fully integrating into care teams, which can impede their ability to contribute effectively to patient care [13]. Future studies should investigate how social workers' roles can be better recognized and integrated within interdisciplinary teams to improve patient and worker outcomes.

Finally, the literature lacks a thorough examination of the innovative approaches that could enhance the sustainability of medical social work in hospice settings. There is a pressing need for evidence-based strategies that improve patient outcomes and support social workers' well-being. For example, exploring the impact of mindfulness interventions on hospice workers' well-being could provide insights into effective coping mechanisms [77]. Moreover, understanding how healthcare systems globally recognize and integrate social work roles in hospice care can inform best practices and policy recommendations [78]. By addressing these gaps, future research can contribute to a more robust understanding of the multifaceted role of social workers in hospice care, ultimately leading to improved care for patients and families during one of the most challenging times in their lives.

8. Conclusion

Medical social workers are indispensable in hospice care, addressing the complex intersection of clinical and emotional needs during end-of-life care. Their expertise in psychosocial assessment forms the backbone of patient-centered care, guiding interdisciplinary teams to develop culturally sensitive and tailored care plans. By navigating the social, emotional, and financial challenges patients and families face, these professionals provide holistic support that complements clinical interventions. This integration improves the quality of life for patients and alleviates the emotional and logistical burdens on families and the broader healthcare system. Their contributions align with global goals for equitable and sustainable healthcare, ensuring that vulnerable populations receive compassionate, dignified, and comprehensive care.

Furthermore, integrating social work into hospice care fosters sustainable healthcare practices by addressing root causes of distress and enhancing communication within interdisciplinary teams. Medical social workers ensure that care's psychological, social, and spiritual dimensions are not overlooked, creating a more inclusive and practical approach to end-of-life care. As healthcare systems evolve, the role of these professionals becomes increasingly vital for driving systemic change that promotes equitable access and quality care. Their work exemplifies the necessity of a multidisciplinary framework that meets the diverse needs of patients and families with empathy and effectiveness. Strengthening support for hospice social workers through training, resource allocation, and organizational collaboration will ensure the evolution of compassionate, patient-centered end-of-life care.

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Review

Biodiversity and renewable energy in a warming world: Pathway to mitigate climate change while preserving ecosystem

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Abstract: This review examines the dual roles of renewable energy in mitigating climate change and preserving biodiversity. It looks at the direct and indirect impacts of renewable energy on biodiversity and highlights strategies for striking a balance between energy development and ecological conservation. The global climate crisis demands immediate action, and renewable energy is a key component of efforts to mitigate climate change. However, while renewable energy technologies like solar, wind, and bioenergy hold significant potential to reduce greenhouse gas emissions, their deployment also presents risks to biodiversity. The relationship between renewable energy and biodiversity conservation is complex, as energy infrastructure can cause habitat destruction, ecosystem disruptions, and habitat fragmentation, potentially aggravating the very environmental challenges that renewable energy seeks to address. Whereas renewable energy technologies can lessen the environmental impact of human activity, their widespread use may have unforeseen effects on species and ecosystems. If not properly managed, renewable energy projects have the potential to cause major changes in land use, including desertification, deforestation, and the disruption of delicate ecosystems. Ecosystems may also be harmed by the exploitation of raw resources for renewable energy, such as lithium for batteries and rare earth elements for wind turbines. This review examines the main obstacles to coordinating the growth of renewable energy with the preservation of biodiversity, including the effects of wind farms on bat and bird populations, the way hydropower dams change river ecosystems, and the possibility that bioenergy crops would supplant native flora. It then suggests ways to lessen these effects, such as improved site design, more effective energy systems, and incorporating biodiversity concerns into legislative frameworks. In order to guarantee that renewable energy contributes to a sustainable future for both climate and biodiversity, the study concludes by highlighting the necessity of a multidisciplinary strategy that combines energy and conservation policy.

Keywords: biodiversity; renewable energy; climate change; ecosystem

1. Introduction

Rising temperatures, more intense weather, and changing ecological patterns are all signs of the growing climate problem, which has emerged as one of the 21st century's most significant issues. Carbon dioxide concentrations in the atmosphere have reached previously unheard-of levels due to human activity, specifically the burning of fossil fuels, deforestation, and industrial operations [1]. The richness of life on Earth, or biodiversity, has been declining at startling rates at the same time, with species extinction happening 1000–10,000 times faster than the natural background rate [2]. These two crises are not only related but also reinforce one another since biodiversity loss is made worse by climate change, and ecosystems

become less resilient to the effects of climate change when biodiversity declines. Changes in species distributions, altered habitats, and a rise in invasive species and diseases are some of the ways that climate change impacts biodiversity. Warming temperatures force species over their physiological limitations, resulting in population decreases and extinctions, while rising sea levels endanger coastal habitats [3]. Often referred to as the "rainforests of the sea", coral reefs are one of the ecosystems most at risk from climate change. The livelihoods of millions of people who rely on these ecosystems are in danger due to widespread coral bleaching and mortality brought on by ocean acidification and thermal stress brought on by rising carbon dioxide levels [4]. On the other hand, biodiversity is essential for reducing the effects of climate change. Mangroves, marshes, and forests all serve as organic carbon sinks, removing enormous volumes of carbon dioxide from the atmosphere [2].

However, there are environmental consequences associated with the expansion of renewable energy infrastructure. Large-scale solar farms frequently necessitate a large amount of land, which causes species displacement and habitat fragmentation. Despite being an essential part of clean energy, wind turbines can endanger bat and bird populations, especially if they are situated along migratory routes [5]. By changing fish migration patterns, sediment transport, and water flow, hydropower dams disturb river ecosystems [6]. Food security issues may worsen if bioenergy plantations are not managed properly since they may cause deforestation and compete with food crops [7]. These compromises highlight how crucial it is to incorporate biodiversity concerns into the design and application of renewable energy. Adopted in 2015, the Paris Agreement highlights the need for equitable and effective climate action [8]. This entails acknowledging how climate and biodiversity goals are interdependent and making sure that actions taken to slow down climate change don't harm ecosystems. For example, carefully placing renewable energy plants in low-biodiversity or degraded areas might maximize climatic benefits while minimizing ecological consequences [9]. Technological innovations like bio-inspired wind turbine designs and floating solar farms provide creative ways to lessen the environmental impact of renewable energy systems [10,11].

Significant gaps still exist in converting policy pledges into practical tactics on the ground, notwithstanding these efforts. Governments, businesses, researchers, and communities must work together to close these gaps and create comprehensive strategies that strike a balance between biodiversity and climate goals. Additionally, renewable energy may help alleviate economic and social disparities. Off-grid solar solutions and other decentralized renewable energy systems can supply electricity to isolated and underprivileged areas, enhancing their standard of living and promoting economic growth. Residents are empowered by community-owned renewable energy projects, which guarantee that the advantages of clean energy are shared fairly [12]. Similar to this, incorporating green infrastructure into renewable energy projects—like wildlife corridors and vegetated buffers—can lessen ecological effects and promote ecosystem functioning [13]. Although there are many obstacles to overcome, coordinating the growth of renewable energy with the preservation of biodiversity is not impossible. Climate and biodiversity goals can be harmoniously

balanced by using a system-based approach that takes ecological, social, and economic factors into account. In order to provide a path for a transition to renewable energy that is sensitive to biodiversity, this review attempts to clarify these potential and obstacles. We examine how renewable energy might help mitigate climate change, how renewable energy technologies affect biodiversity, and how to match the use of renewable energy with conservation objectives in the parts that follow. This paper aims to contribute to the current discussion on sustainable development in a warming world by providing a thorough synthesis of the body of existing material.

2. Literature review

The body of research on the connection between renewable energy and biodiversity is extensive and identifies both potential and problems. Research continuously demonstrates that habitat loss, species migration, and changed ecosystem dynamics are just a few of the direct and indirect impacts of climate change on biodiversity. When not properly designed, renewable energy might unintentionally lead to habitat fragmentation and ecological disruption even when it is reducing the effects of climate change [14,15]. Another major topic has been the interaction between offshore wind farms and marine species. Bailey et al. [14] shed light on these installations' dual function as possible marine ecosystem disruptors and enhancers [7]. Technological innovations like floating solar panels and bird-safe wind turbines are examples of continuous attempts to balance the development of renewable energy with the preservation of biodiversity [16,17]. Another crucial area of research is governance systems and policy frameworks. The goal of the EU's Renewable Energy Directive and related regulations is to strike a balance between environmental preservation and energy expansion [11]. Furthermore, the necessity of worldwide initiatives to incorporate biodiversity into energy planning is highlighted by international partnerships like the Convention on Biological Diversity (CBD) [18].

2.1. The Implications and interactions of climate change on biodiversity

One of the biggest risks to biodiversity is climate change. Ecosystems are disrupted by rising temperatures, changing precipitation patterns, and an increase in the frequency of extreme weather events, which force species to migrate or adapt (**Figure 1**). But not all species can adapt to the changing environment or relocate fast enough [19]. Certain ecosystems, including wetlands and coral reefs, are especially susceptible to even minor changes in weather and temperature, which can result in the extinction of species and the loss of ecosystem services [20]. Overuse of natural resources and habitat destruction exacerbate the detrimental effects of climate change on biodiversity. Human-induced ecosystem change is hastening the loss of biodiversity (**Figure 1**), which has significant ramifications for ecosystem resilience [21]. To prevent one catastrophe from exacerbating the other, it is imperative that the climate crisis and biodiversity loss be addressed together.

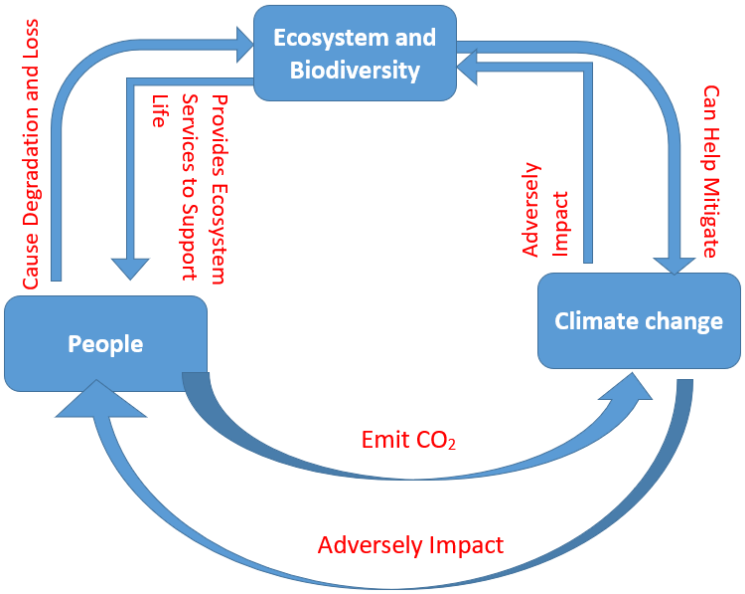

Figure 1. Ecosystem-based adaptation and climate change mitigation.

2.2. The function of renewable energy technologies in climate mitigation

Renewable energy technologies are critical to mitigating the effects of climate change. The following sections discuss the environmental benefits and challenges of each renewable energy source.

Bioenergy production often involves land-use changes, such as converting forests into plantations, which can lead to biodiversity loss [7]. Monoculture plantations, commonly used for bioenergy crops, provide limited habitat value compared to natural ecosystems. Sustainable practices, such as integrating agroforestry, can mitigate these impacts while maintaining carbon sequestration benefits [22]. Bioenergy systems also offer opportunities for waste utilization. For example, agricultural and forestry residues can be used as feedstock for bioenergy production, reducing the need for additional land conversion. Advances in bioenergy technologies, such as cellulosic ethanol and algae-based biofuels, hold promises for enhancing sustainability and reducing ecological impacts. Wind Power: With the quantity and capacity of wind farms growing quickly, wind energy plays a significant role in the world's renewable energy supply. However, local species, particularly birds and bats, which are susceptible to accidents, may suffer because of wind turbines [23]. Additionally, wind farm construction can disturb migratory pathways and fragment habitats [24]. These effects can be lessened by innovations in turbine design, such as offshore wind farms and smaller, quieter models [6].

Solar energy is one of the most promising renewable energy sources. Concentrated solar power (CSP) plants and photovoltaic (PV) cells have seen significant improvements in scale and efficiency [25]. Solar power helps decarbonize energy systems and reduces dependency on fossil fuels, but large-scale solar projects can require a lot of land, which could potentially displace sensitive ecosystems [26]. For instance, in desert ecosystems, large-scale solar installations may disturb delicate

plant and animal communities. These effects (**Table 1**) can be lessened with careful planning and land selection [27].

Table 1. Ecological impacts of solar energy development: Habitat loss, species displacement, and mitigation strategies.

Impact	Description	Mitigation Strategy
Habitat Loss	Conversion of land for solar farms	Site Selection to avoid ecologically sensitive areas, use of degraded land
Species displacement	Loss of species due to habitat disruption	Integration of biodiversity corridors, use of native plant species
Soil degradation	Soil erosion due to land conversion	soil conservation practices, such as erosion control measures

Hydropower, for many years, has been regarded as a dependable renewable energy source. However, massive hydropower projects, like dams, have the potential to drastically change river ecosystems by obstructing fish movement and inundating vast tracts of land [28]. Furthermore, aquatic species and the nearby terrestrial habitats may be impacted by the disturbance of river flows [28]. These effects could be reduced by modifying existing structures or implementing small-scale hydropower projects [6]. For instance, the Noor Ouarzazate Solar Complex in Morocco, one of the world's largest concentrated solar power plants, has significantly reduced the country's carbon footprint. By generating over 580 MW of clean energy, it prevents approximately 760,000 tons of CO_2 emissions annually. This transition to solar power has reduced dependence on fossil fuels, mitigating climate change and protecting biodiversity in desert ecosystems by limiting habitat destruction from mining and fossil fuel extraction [29]. Also, it was reported that Denmark's investment in offshore wind energy has made it a global leader in renewable energy. The Horns Rev wind farms supply a significant portion of the country's electricity while reducing carbon emissions by millions of tons annually. This shift to wind power has not only helped mitigate climate change but also preserved biodiversity by reducing air and water pollution, benefiting marine and terrestrial ecosystems [30].

2.3. Impacts of renewable energy development on the environment

Despite being cleaner than fossil fuels, renewable energy sources nevertheless have a big influence on the environment (**Table 1**). The main issues are as follows:

Habitat destruction and land-use change: The construction of big renewable energy infrastructure, including hydropower dams, solar fields, and wind farms, necessitates a significant amount of land, which could result in habitat fragmentation and destruction (**Table 1**) [27]. For instance, solar farms have the potential to upset delicate plant and animal communities that have adapted to dry environments in desert ecosystems [26].

Resource extraction and biodiversity loss: Metals and rare earth elements must be extracted in order to produce renewable energy technologies. Both terrestrial and aquatic ecosystems may suffer because of habitat damage and environmental degradation brought on by mining for these resources (**Table 1**) [31]. Ecosystems may be harmed by the extraction of lithium and cobalt for batteries used in solar panels and electric cars [32].

Ecosystem service disruption: Hydropower dams and other renewable energy infrastructure can disrupt ecosystem services like nutrient cycling, flood control, and water filtration. Human populations and wildlife may suffer as a result of these disturbances [6].

2.4. Strategies to mitigate renewable energy impacts on biodiversity

To lessen the negative effects of the growth of renewable energy on the environment, several tactics can be used:

Environmentally aware positioning, renewable energy projects should be carefully planned and located to avoid areas of high biodiversity value, migratory corridors, and crucial habitats. Early in the planning process, environmental impact assessments (EIAs) can help direct decision-making and guarantee that possible threats to ecosystems are recognized and reduced [33].

Combining renewable energy with conservation objectives, it is crucial to implement policies that combine biodiversity preservation with renewable energy. For instance, sustainability standards in the European Union's Renewable Energy Directive make sure that renewable energy projects don't negatively impact biodiversity [34]. To guarantee ecologically sustainable development, national energy policy should also take biodiversity into account [7].

New technologies and new developments in renewable energy technology, like offshore wind farms, vertical wind turbines, and floating solar panels, present chances to lessen the environmental effect of energy production while also lessening its effects on ecosystems on land [6]. For example, offshore wind farms can coexist with marine ecosystems and prevent habitat destruction on land [27].

Projects for restoration and reclamation, and renewable energy initiatives may occasionally aid in the repair of the environment. For instance, solar farms that are erected on degraded or abandoned land can produce clean energy and aid in ecosystem rehabilitation [25]. Similar to this, reforestation initiatives in conjunction with the production of bioenergy may foster synergies between the conservation of biodiversity and energy production [35] (**Figure 1**).

2.5. Combining the use of renewable energy with conservation

Planning and Strategic Sitting: The effects on biodiversity can be reduced by strategically placing renewable energy plants. Areas with poor ecological sensitivity can be identified with the use of tools such as GIS-based biodiversity mapping [12]. According to a recent analysis, installing solar panels on damaged areas could help meet the world's energy needs without endangering vital ecosystems [36]. Careful placement to minimize bat habitats and migratory bird pathways is also beneficial for wind energy projects [37]. The idea of "energy sprawl" draws attention to the necessity of coordinated land-use planning to avoid conflicts between conservation objectives and the growth of renewable energy. According to studies, installing renewable energy on lands that have already been degraded or urbanized could greatly lessen the effects on biodiversity while achieving the world's energy goals [10].

Governance and Policy, Long-term sustainability requires that energy policy incorporate biodiversity conservation. In order to guarantee that new projects cause the least amount of ecological disturbance, the EU's Renewable Energy Directive requires environmental studies [11]. Stakeholder participation is best demonstrated by collaborative frameworks such as the Renewable Energy Wildlife Institute in the United States [13]. Furthermore, international accords like the Convention on Biological Diversity (CBD) emphasize the necessity of striking a balance between the conservation of biodiversity and the objectives of renewable energy [18]. Governments are essential in providing incentives for the development of renewable energy sources that support biodiversity. Ecosystem protection and innovation can be achieved through tax credits, subsidies, and regulatory frameworks that give preference to low-impact innovations. Additionally, public-private partnerships provide useful venues for achieving these objectives [38].

Innovations in technology, solutions to lessen ecological footprints, are provided by innovations like bird-safe wind turbines and floating solar panels [16]. Furthermore, improvements in battery storage reduce the amount of land needed to maintain grid stability [39]. New technologies that improve energy efficiency and lessen the need for large land use include bifacial solar panels, which produce power on both sides [40]. The effects of offshore wind farms on marine life are being lessened in the maritime sector thanks to developments in turbine blade design and sound deterrents. In order to lower collision hazards and increase energy generation efficiency, research is being done on bio-inspired engineering, such as wind turbine blades that are shaped like bird wings [17].

2.6. The role of renewable energy on climate change mitigation

Leading the global battle against climate change is renewable energy. Renewable energy sources, including solar, wind, hydropower, and bioenergy, must be adopted if the world is to minimize greenhouse gas emissions. Fossil fuels are the main cause of global warming, yet these technologies provide good substitutes. According to the Intergovernmental Panel on Climate Change (IPCC), switching to renewable energy is crucial to keeping the increase in global temperatures to 1.5 ℃ over pre-industrial levels [1]. The need to switch to renewable energy is urgent since it can both lower emissions and improve energy security. In addition to producing enormous volumes of carbon dioxide, fossil fuel-based energy systems also put energy supply chains at risk. However, substantial expenditures in infrastructure, research, and innovation are necessary to achieve a low-carbon energy future. For example, over the past ten years, solar and wind energy have seen impressive improvements in efficiency and cost reduction. In many areas, solar photovoltaics and onshore wind have significantly reduced their levelized cost of energy (LCOE), making them competitive with or even less expensive than fossil fuels [9].

The promotion of renewable energy is becoming more and more vital to the global policy environment. Adopted in 2015, the Paris Agreement is a historic pledge to reduce greenhouse gas emissions in order to fight climate change [8]. Countries have established nationally determined contributions (NDCs) within this framework that specify their goals for renewable energy and emission reduction.

Another example of a comprehensive legislative framework designed to increase the deployment of renewable energy is the Renewable Energy Directive of the European Union [34]. Setting enforceable goals for member states to attain a specific percentage of renewable energy in their energy mix, this directive places a strong emphasis on sustainability. In a similar vein, nations like the US, China, and India have put ambitious plans for renewable energy into action to spearhead the worldwide shift. The adoption of renewable energy varies greatly by location, notwithstanding these efforts. Developing nations frequently struggle with issues including restricted access to grid infrastructure, funding, and technology. In order to close these gaps and assist renewable energy initiatives in these areas, international collaboration and financial tools like the Green Climate Fund are essential.

Renewable energy has grown rapidly due in large part to technological breakthroughs. Photovoltaic cells and concentrated solar power systems are two examples of solar energy technologies that have improved efficiency and affordability. In a similar vein, wind turbine designs have improved to better capture wind energy, especially in regions with low wind speeds [10]. Lithium-ion and enhanced flow batteries are two examples of energy storage technologies that are essential for mitigating the intermittent nature of renewable energy sources. These technologies make it possible to store extra energy produced during periods of high production for use during periods of low production. Reliability is increased, and the requirement for fossil fuel backup power is decreased when storage technologies are integrated into renewable energy grids. Energy systems are also being revolutionized by digital solutions and smart grid technologies. Demand-response management, real-time monitoring, and efficient energy distribution are made possible by these advancements. Additionally, smart grids make it easier to incorporate dispersed energy sources into the larger energy system, such as community wind projects and rooftop solar panels.

In addition to reducing global warming, renewable energy has many other advantages. For example, using renewable energy sources lowers air pollution, which has important economic and health effects. The burning of fossil fuels is a significant source of air pollutants such as nitrogen oxides, sulfur dioxide, and particulate matter. Making the switch to sustainable energy sources can lower the prevalence of cardiovascular and respiratory illnesses and greatly improve air quality [11]. Projects using renewable energy also generate revenue. Compared to fossil fuels, the renewable energy industry is labor-intensive and creates more jobs per unit of energy produced. Over 12 million people were engaged worldwide in the renewable energy sector in 2020, according to the International Renewable Energy Agency (IRENA), and this figure is projected to rise as more money is invested in renewable energy sources [12]. Additionally, in isolated and neglected locations, renewable energy can improve electricity availability. For areas without access to centralized power grids, decentralized renewable energy sources like microgrids and off-grid solar solutions supply electricity. This promotes social justice and economic growth in addition to raising living standards.

Renewable energy has many advantages; however, there are drawbacks to its use. The main challenges include resource shortages, land-use conflicts, and technical restrictions. Large-scale solar farms, for instance, demand a lot of land,

which may cause habitat degradation and conflict with farming [25]. In a similar vein, the extraction of rare earth metals and lithium for renewable energy technology has social and environmental ramifications [32]. Researchers and policymakers are looking at creative ways to solve these problems. One strategy that maximizes land use while promoting food and energy production is agrivoltaics, which blends solar energy generation with agriculture [22]. Installed on reservoirs and other bodies of water, floating solar farms provide additional advantages, including less water evaporation and enhanced panel efficiency [11]. To overcome these obstacles, parties must work together. To create and execute policies that support sustainable renewable energy practices, governments, business leaders, academic institutions, and civil society organizations must collaborate. For example, public-private partnerships can pool resources and knowledge to spur innovation and increase the use of renewable energy [36].

Making the switch to a low-carbon economy egalitarian and inclusive is ensured by a just transition to renewable energy. This entails addressing the economic and social effects of moving away from fossil fuels, especially for workers and communities who rely on the fossil fuel sector. A just transition requires policies that promote community growth, social safety nets, and workforce retraining. For instance, in areas that have historically relied on coal mining or oil extraction, investments in renewable energy projects can generate alternative job prospects. Furthermore, community ownership models for renewable energy projects guarantee that the advantages of clean energy are shared fairly and strengthen local communities. Resolving past disparities in energy access is another aspect of the idea of energy justice. An opportunity to close the energy gap and guarantee that underserved populations have access to reasonably priced, dependable, and clean electricity is presented by renewable energy. Prioritizing the needs of disadvantaged people through targeted policies and investments is necessary to achieve energy justice.

Integrating renewable energy with other sustainable development objectives is key to its future. For example, coordinating renewable energy initiatives with biodiversity preservation can result in synergies that advance ecological and climate goals. When combined with sophisticated spatial analysis methods, landscape-level planning can pinpoint locations where the use of renewable energy has the least negative ecological effects [38]. Innovation will be essential to the development of renewable energy technology. Research on bioenergy feedstocks, enhanced wind turbine materials, and next-generation solar cells have the potential to improve sustainability and efficiency. Furthermore, waste may be minimized, and resource consumption can be decreased by developing circular economy models for renewable energy systems. International collaboration will be essential to the global expansion of renewable energy. Financial tools, capacity-building programs, and knowledge-sharing platforms can all aid in closing the gap between industrialized and poor nations. The switch to renewable energy can become a pillar of global climate action by encouraging cooperation. In summary, renewable energy provides a route to a resilient and sustainable future and is essential for mitigating the effects of climate change. However, the values of equality, creativity, and sustainability must direct its implementation. Renewable energy has the potential to be a game-

changer in the worldwide fight against climate change if the obstacles are addressed and the opportunities are taken advantage of.

Moreover, using an environmental impact factor such as carbon footprint (CF) to assess the benefits of renewable energy in mitigating climate change and preserving biodiversity allows for a standardized comparison of different energy sources [1,8]. CF measures greenhouse gas emissions associated with energy production, making it easier to quantify the environmental benefits of renewables like solar, wind, and hydropower compared to fossil fuels. Renewable energy sources significantly reduce CF by replacing carbon-intensive fuels, lowering atmospheric CO_2 levels, and decreasing global warming effects [8,25]. This, in turn, helps preserve ecosystems by reducing habitat destruction caused by climate change, such as coral bleaching, deforestation, and species loss. Lower emissions also minimize air and water pollution, benefiting biodiversity by improving habitat quality [25]. By using CF as a common criterion, policymakers and stakeholders can evaluate the effectiveness of various climate action strategies, prioritize low-impact energy solutions, and set measurable sustainability goals. This approach enhances transparency, supports informed decision-making, and promotes global efforts to combat climate change while safeguarding biodiversity. Ultimately, integrating CF into energy planning fosters a transition to cleaner energy systems, ensuring environmental sustainability and resilience for future generations.

2.7. The role of ecosystems in mitigating climate change

Because they operate as carbon sinks, absorbing and storing atmospheric carbon dioxide (CO_2), ecosystems are essential to reducing the effects of climate change [41]. In this context, soil, marshes, and forests are especially important. Through photosynthesis, forests—particularly tropical rainforests—sequester significant amounts of CO_2, and soil carbon storage is crucial to sustaining the global carbon cycle [1]. Peatlands can store up to one-third of the carbon in the soil on Earth, making them one of the most effective carbon sinks [17]. With mangrove forests storing up to four times more carbon per unit area than terrestrial forests, coastal habitats like salt marshes, seagrass beds, and mangroves are especially essential for sequestering carbon [41]. Additionally, ecosystems with more biodiversity are better able to store carbon and are more resilient to the effects of climate change [20,42]. In order to improve these ecosystems' potential to store carbon and lessen the effects of climate change, while also preserving biodiversity and ecosystem services, it is imperative that they be preserved and restored [42,43].

2.8. Trade-offs between renewable energy and ecosystems

Loss of Habitat and Land Use, Large-scale renewable energy initiatives, such as wind turbines and solar farms, need a lot of land and may intrude on natural areas [14,15]. Developments in wind energy in the United States have affected important bird migration pathways, leading to higher mortality rates, according to a 2021 study [44]. In dry areas, solar farms have the potential to disrupt delicate desert ecosystems [45]. When grown on a big scale, land-intensive bioenergy crops like oil palms and maize worsen habitat loss [9]. Integrated land-use planning is necessary to balance

biodiversity conservation with the land requirements of renewable energy. Innovative approaches that combine solar energy generation with agricultural practices, such as agrovoltaics, present intriguing ways to maximize land usage while reducing environmental trade-offs [46].

Offshore Renewables' Effects on the Marine Environment: Although they have significant energy potential, offshore wind farms have the potential to disturb marine ecosystems [22]. Fish migration patterns can be changed by turbine blades, and marine mammals are impacted by noise pollution during construction [47]. It is crucial to implement mitigation strategies like exclusion zones and quieter construction technologies [47]. The multiple impacts of offshore wind farms are highlighted by the fact that they can produce artificial reef structures that promote marine biodiversity [44,47]. For marine biodiversity, the development of tidal and wave energy technology brings both new opportunities and challenges. The undersea infrastructure of these technologies can disrupt the natural habitats and behaviors of marine creatures, even though their visual consequences are less than those of offshore wind. To reduce these effects, adaptive management techniques and strategic siting are crucial [46,47].

3. Future directions

Future research should focus on optimizing renewable energy site selection using advanced Geographic Information Systems (GIS) and remote sensing to minimize habitat destruction. Developing biodiversity-friendly technologies, such as bird-friendly wind turbines and fish-friendly hydropower systems, can help reduce ecological impacts. Additionally, sustainable resource extraction methods for materials like lithium and rare earth elements must be prioritized to prevent habitat degradation. Stronger policy integration is needed, ensuring that renewable energy expansion aligns with conservation strategies. This includes enhancing environmental impact assessments (EIAs) and promoting ecological compensation measures. Community engagement and indigenous knowledge should also play a crucial role in planning renewable energy projects to balance development with local ecosystem protection. Finally, interdisciplinary collaborations between energy developers, conservationists, and policymakers can lead to innovative solutions that maximize climate benefits while safeguarding biodiversity. Addressing these challenges will be essential for a truly sustainable energy transition.

4. Conclusion

Transitioning to renewable energy is essential for mitigating climate change, but its potential impacts on biodiversity must be carefully managed. While solar, wind, hydropower, and bioenergy significantly reduce greenhouse gas emissions, their large-scale deployment can lead to habitat destruction, species displacement, and ecosystem fragmentation if not properly planned. Addressing these challenges requires a comprehensive approach that integrates energy development with biodiversity conservation. Strategic site selection, particularly avoiding ecologically sensitive areas, is crucial in minimizing environmental harm. Technologies such as floating solar farms, offshore wind farms, and sustainable bioenergy practices can

reduce land-use conflicts and ecological disruption. Additionally, innovations like bird-friendly wind turbines and fish-friendly hydropower systems can help mitigate species loss. Strengthening environmental impact assessments (EIAs) and ensuring compliance with biodiversity protection regulations will be key to balancing energy expansion with conservation. Policymakers must prioritize biodiversity alongside energy development to ensure that climate goals do not come at the cost of ecosystem health. Integrating biodiversity safeguards into energy policies, promoting ecological compensation measures, and encouraging interdisciplinary collaboration among scientists, conservationists, and energy developers are necessary steps toward a balanced approach. Community engagement and the incorporation of indigenous knowledge can further enhance the sustainability of renewable energy projects. As the world continues to scale up renewable energy, developing comprehensive guidelines and best practices is essential to aligning energy production with ecosystem protection. By adopting a multidisciplinary, ecosystem-based approach, it is possible to expand renewable energy while preserving biodiversity. Protecting ecosystems not only strengthens resilience against climate change but also ensures long-term environmental sustainability and human well-being. A holistic approach that considers both climate and biodiversity will be critical for achieving a truly sustainable energy transition.

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